

## Sample Collection Methods

Consistent with the Division of Water's other ambient groundwater monitoring efforts, samples of fresh, untreated groundwater were collected at each spring or well and analyzed for major inorganic ions; nutrients; volatile organic compounds; total organic carbon; pesticides, including the most commonly used herbicides, insecticides and fungicides; and dissolved and total recoverable metals. The analytical methods, containers, volumes collected, preservation and sample transport are consistent with the Division of Water's Kentucky Ambient/Watershed Water Quality Monitoring Standard Operating Procedure Manual, prepared by the Water Quality Branch (2002c). Parameters to be measured, volume required for analysis, container type and preservative are shown on the attached Chain-of-Custody Form (Appendix F).

Major inorganic ions are used to establish background groundwater chemistry and also to measure impacts from nonpoint source pollutants such as abandoned mine lands and abandoned hydrocarbon production operations by measuring pH, alkalinity, chloride, sulfate and fluoride. Nutrients and total organic carbon are used to measure impacts from agricultural operations (ammonia, nitrate-n, nitrite-n, total Kjeldhal nitrogen, total phosphorous and orthophosphate) and/or improper sewage disposal (nitrates, ammonia). Where sewage was suspected as a nonpoint source pollutant, unbleached cotton fabric swatches were used to detect optical brighteners, the whitening agents used in laundry products and commonly found in sewage (Quinlan, 1986). Pesticides are measured to determine both rural agriculture and urban domestic- and commercial-use impacts on groundwater. Metals are useful to establish rock-groundwater chemistry, local and regional background levels and to determine nonpoint source impacts from active or abandoned coal mining operations. Volatile organic compounds determine impacts from urban run-off, oil and gas production, or other point and nonpoint source impacts to groundwater.

Sampling for pathogens was not conducted because of logistical considerations. Sampling at numerous sites occurred over a one- or two-day period, commonly in remote regions. Because of the short holding time for bacteria (6 hours for fecal coliform, 24 hours for total coliform) we were unable to sample efficiently and regularly collect bacteria samples and comply with the required holding times.

All samples collected to meet grant commitments were analyzed by the Division of Environmental Services (DES) laboratory according to appropriate U.S.EPA methods. Additional data included in this study are from samples analyzed by DES for other groundwater projects, as well as data from the Kentucky Geological Survey laboratory. Appropriate U.S.EPA analytical methods were employed for all data used in this report.

## **RESULTS and DISCUSSION**

### **Introduction**

General water quality information, including definitions and sources, were compiled from numerous sources, primarily Hem (1985), USGS (2002a) and Driscoll (1986). Potential impacts to human health were compiled from the United States Environmental Protection Agency (U.S.EPA, 2002a) and the Agency for Toxic Substances and Disease Registry (ATSDR, 2001).

Parameters were divided into seven categories: hydroparameters (which includes conductivity, hardness and pH), inorganic ions, metals, pesticides, residues, volatile organic compounds and nutrients.

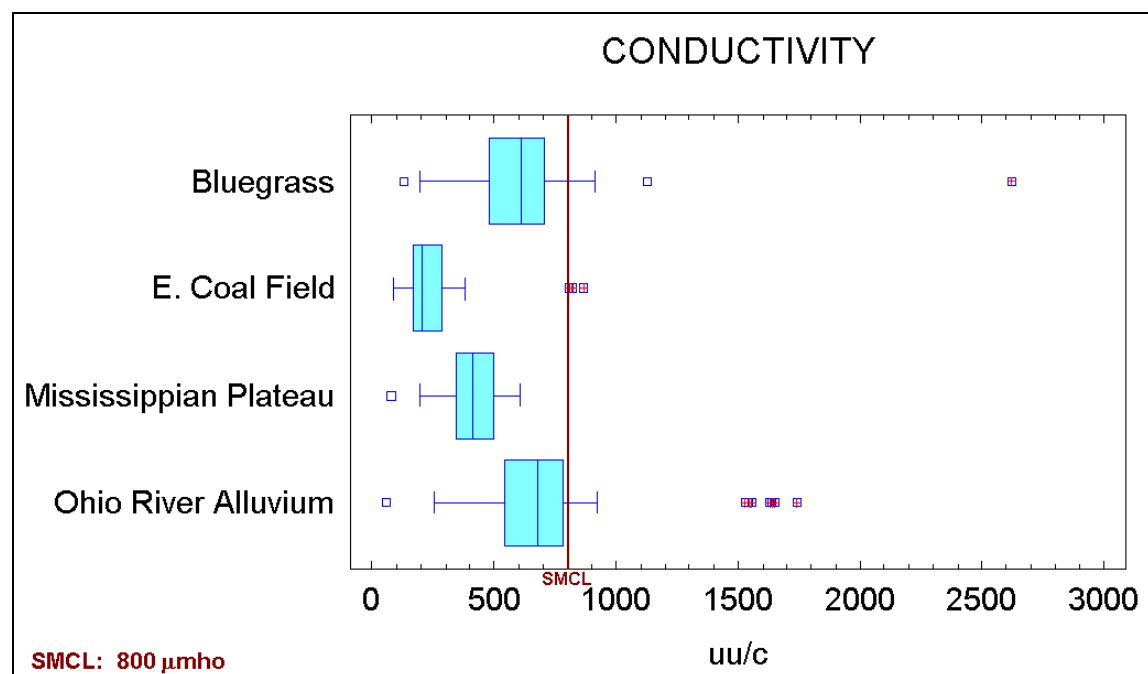
### **Hydroparameters (conductivity, hardness and pH)**

Conductivity, also known as specific conductance, is a measurement of the ability of water to conduct electrical current (Hem, 1985) and is reported in microsiemens ( $\mu\text{S}/\text{cm}$ ). Since a microsiemen is the reciprocal of an **ohm**, the spelling of that latter unit has been reversed as an equivalent unit used to report conductivity. The term for a microsiemen reported in these units is " **$\mu\text{mho}$** ." Some laboratories report this as " **$\text{uU}/\text{cm}$** ". Therefore,  $800 \text{ mS}/\text{cm} = 800 \mu\text{mho} = 800 \text{ uU}/\text{cm}$ . There is no MCL or other

regulatory standard for conductivity; however, 800  $\mu\text{mho}$  corresponds roughly to the 500 mg/L SMCL for Total Dissolved Solids, or TDS. Because conductivity increases as the amount of dissolved ions increases, it may be used as a general indicator of water pollution. However, caution should be exercised in the interpretation of conductivity results, as naturally occurring ions dissolved in water will result in elevated measurements. These ions include chloride, sulfate, iron, carbonate, calcium and others.

The boxplot for conductivity (Figures 5 and 6) showed a wider variation in values for the

**Figure 5. Boxplot for Conductivity measurement distributions in BMU #2**



Bluegrass and the Ohio River Alluvium than for the other physiographic provinces. In the Bluegrass, this is most likely the result of the natural variability of Total Dissolved Solids (TDS) in this system consisting largely of soluble carbonate bedrock. Lower values in the Eastern Coal Field most likely result from the prevalence of clastic sedimentary rocks, which are less soluble than the karstic, more readily dissolved carbonate rock predominating in the Bluegrass and Mississippian Plateau. Relatively high values in the Ohio River Alluvium may result from longer residence times of groundwater in these

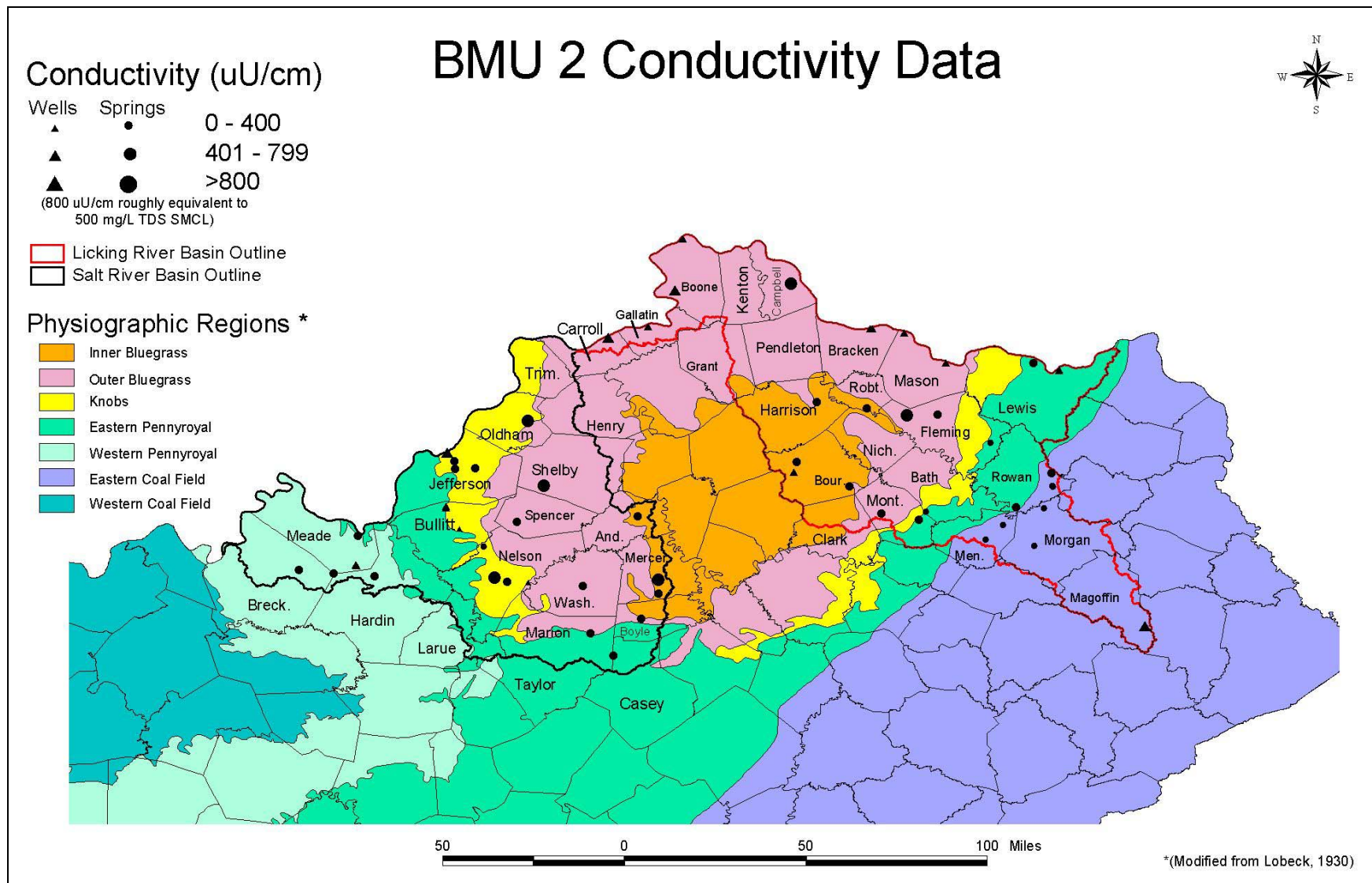


Figure 6. Map of conductivity data in BMU 2

heterogeneous, unconsolidated sediments. Conductivity values found in this study are comparable to those found by Carey and others (1993). In their study of 4,859 groundwater analyses throughout the state, an average value of 495 uU/cm was found, compared to a median value of 578 uU/cm for the 314 samples included in this study. Because conductivity measures a variety of ions, most of which are naturally occurring, the interpretation of this parameter alone as an indicator of nonpoint source pollution is difficult. Absent any direct evidence to the contrary, the range of values found in this study most likely reflect ambient conditions and are not necessarily indicative of nonpoint source pollution.

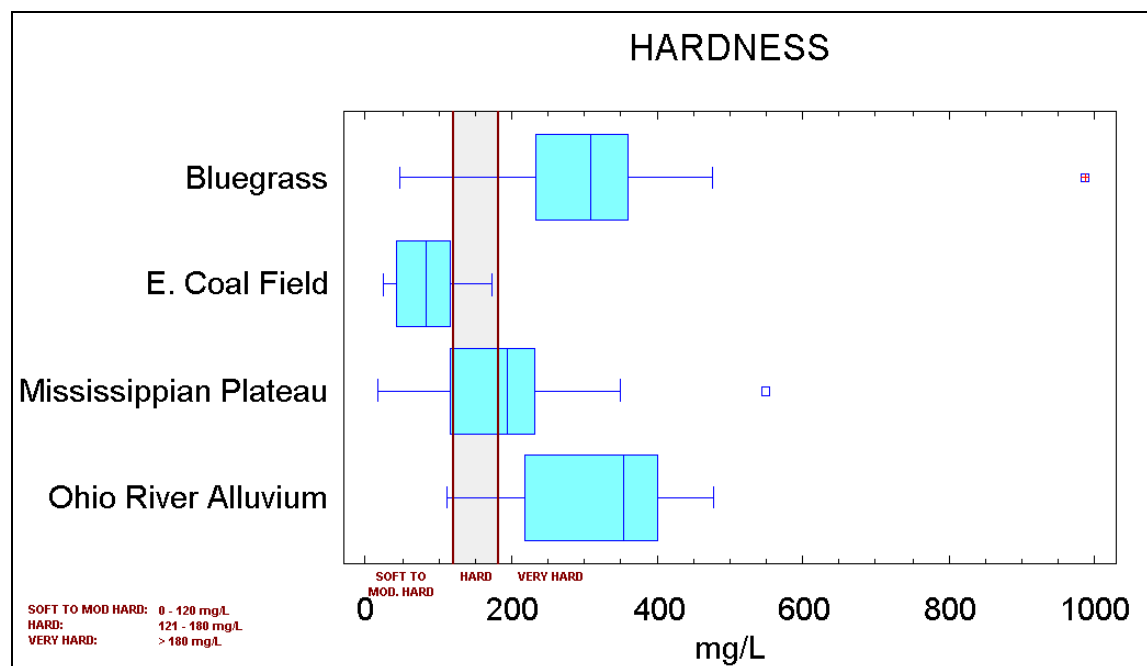
The term “hardness” was first used to describe water that was hard to lather. Water is made hard primarily from dissolved calcium and magnesium. Hardness measures the ability of water to produce soap lather, or suds and is reported as equivalent  $\text{CaCO}_3$  in mg/L derived from:  $(2.5 \times \text{mg/L Ca}) + (4.1 \times \text{mg/L Mg})$ . Hardness typically causes scaling on water pipes, boilers and in cooking pans, causing problems in the laundry, kitchen and bath. Water with excessive hardness may taste chalky, salty, or metallic, depending on the relative concentrations of various dissolved compounds. On the other hand, very soft water often has a flat, unpleasant taste. Most consumers, therefore, prefer to drink water of moderate hardness.

No regulatory standards exist for hardness. The Water Quality Association (2002) hardness scale has been modified for this report, where soft water is defined as less than 17 mg/L of calcium/magnesium, water from 17.1 to 120 mg/L is moderate and more than 120 mg/L is hard.

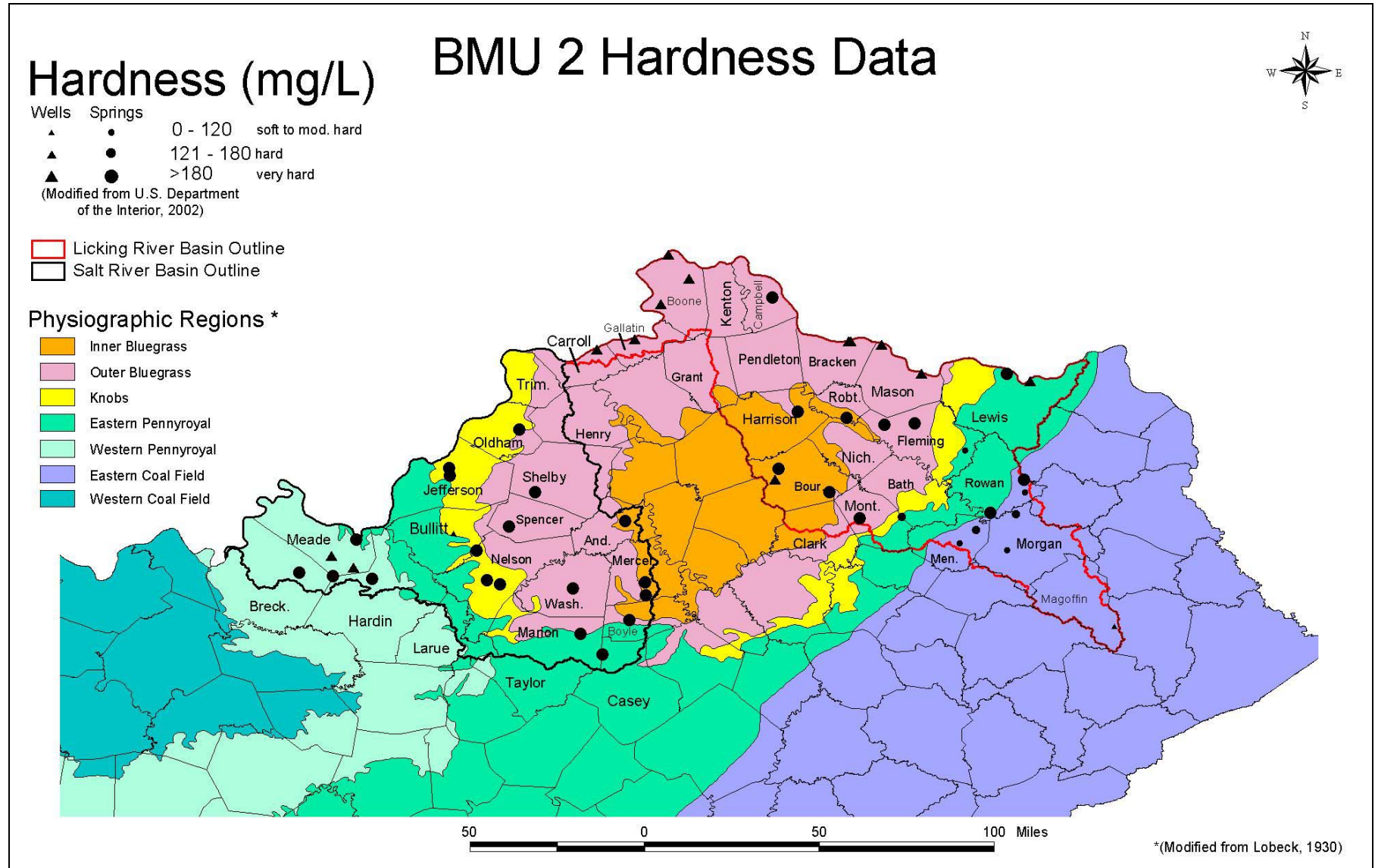
The boxplot illustrating the distribution of hardness values (Figure 7) shows that median values for groundwater are very hard in all physiographic provinces of BMU 2, except the Eastern Coal Field. This reflects the abundance of calcium and magnesium, mostly derived from carbonate sedimentary rocks, in the Bluegrass, Mississippian Plateau and Ohio River alluvial aquifer. This is indicative of ambient conditions, rather than of nonpoint source impacts.

Hardness values are generally high in both springs and wells throughout the study area (Figure 8). Lowest values are in the Eastern Coal Field in which clastic sedimentary rocks, generally low in calcium and magnesium, are dominant.

Figure 7. Boxplot for Hardness measurement distributions in BMU #2



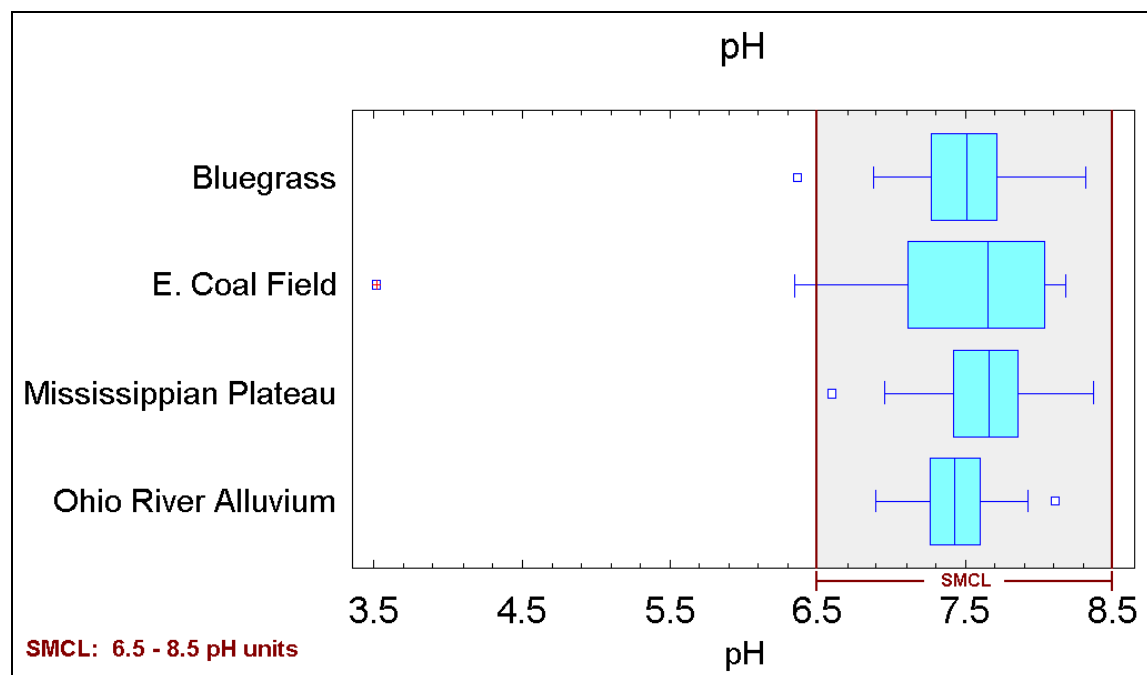
pH is the negative log of the concentration of the hydronium ion and is essentially a measure of the relative acidity or alkalinity of water. The units of pH are dimensionless, and the scale measures from 0 to 14. In this system, 7 represents neutral pH and values less than 7 are more acidic; values greater than 7 are more alkaline. The relative acidity/alkalinity of water is important in regard to water quality because this affects several qualities: the corrosiveness of the water, the ability to dissolve contaminants such as heavy metals, the taste of the water for human consumption and in general the overall usefulness of water for various industrial functions. The pH range of normal aquatic systems is between 6.5 and 8.0. Low pH levels can indicate nonpoint source impacts from coal mining or other mineral extraction processes. High pH values for groundwater may indicate nonpoint source impacts to groundwater from brine intrusion from current or former oil and gas exploration and development activities. Concerning potability, pH is an aesthetic standard, with an SMCL range of 6.5 to 8.5 pH units.



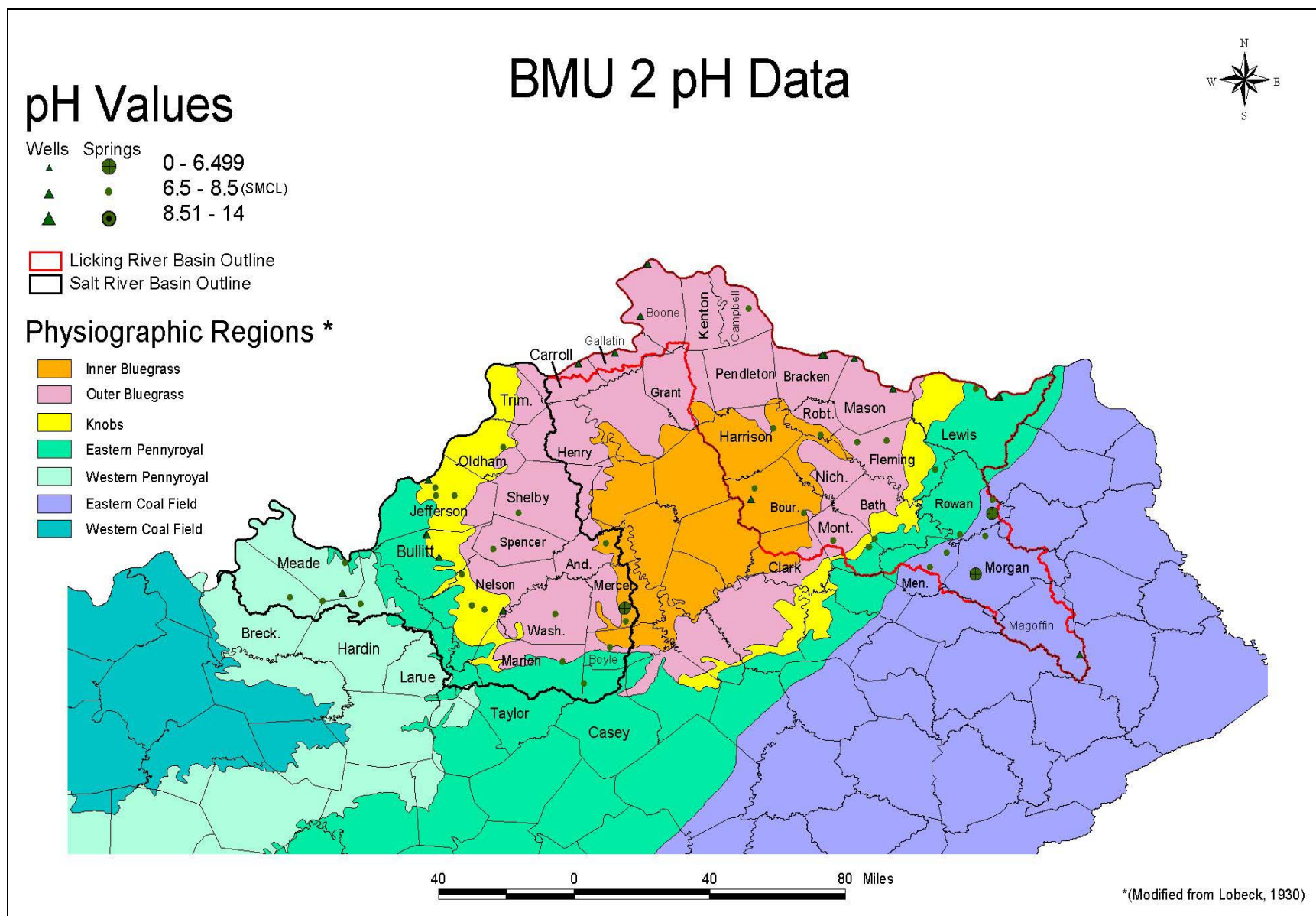
**Figure 8. Map of hardness data in BMU 2**

Figures 9 and 10 show that almost all pH values are within the SMCL range of 6.5 to 8.5 units. The greatest variability is in the Eastern Coal Field, with the outliers at approximately 3.5 and 6.4 pH

**Figure 9. Boxplot for pH measurement distributions in BMU #2**



units (from Magoffin and Rowan Counties). The first measurement is from a one-time only sampling event at a site draining predominately carbonate rocks of Mississippian-age and is anomalous and unexplained. The later site is in an unmined area dominated by Pennsylvanian-age sedimentary rocks, including coal, and may represent naturally occurring conditions. Based on current knowledge of both sites, neither nonpoint source pollution. The other physiographic provinces show natural variability, and because there is no direct evidence of nonpoint source influences on pH in areas adjacent to the studied sites, the conclusion is that there are no probable impacts from nonpoint source pollution. The outlier in the Bluegrass occurred at Humane Spring in Mercer County. This site has known impacts from a manufacturing facility point source. This site is monitored in support of the Kentucky Division of Waste Management's oversight of remediation at this facility and to provide additional long-term data from this source, as well as to document possible future impacts from further development in this area.



**Figure 10. Map of pH Data for BMU 2**

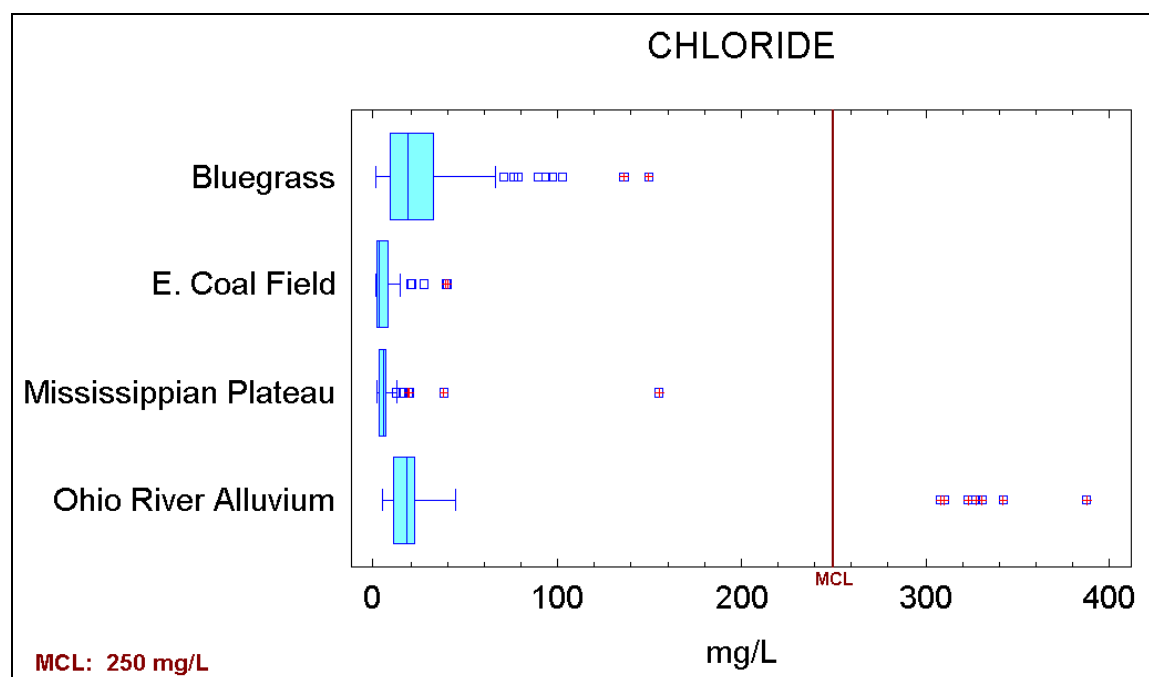
The low pH values discussed above occur in Magoffin and Rowan counties, in the Eastern Coal Field, but do not appear to indicate nonpoint source pollution.

### **Inorganic Ions (chloride, fluoride and sulfate)**

Chloride (Cl) is naturally occurring in most rocks and soils and is the primary constituent that makes water "salty". Chloride also occurs in sewage, industrial brines and in urban runoff from the application of road salt. Brine water, or "connate water", occurs in the pore spaces and fractures of rocks and is sometimes found at shallow depths, especially in eastern Kentucky. Typically, however, water gradually becomes saltier as the depth increases. Over-pumping of fresh water in some wells can induce chloride-rich brines which occur at depth to move, or "up well," toward the discharge point. This phenomenon is known as "salt water intrusion." As nonpoint source pollutants, chlorides are also associated with crude oil and are commonly produced as a by-product when oil is pumped to the surface. For disposal, these brines are typically re-injected into very deep and already briny, formations. Further, chloride-rich brines can contaminate freshwater aquifers through improperly cased or abandoned oil production wells.

In general, the boxplot for chloride (Figure 11) shows low chloride values in BMU 2. In Kentucky, high chlorides sometimes occur at shallow depths and because no specific point sources of chlorides occur adjacent to the sites sampled in this study, the variation observed is probably natural. The highest values found in this study were for a test well pumped continuously for long periods in the Ohio River Alluvium at Louisville (Figure 12). High chloride values in this well may result from the intrusion of chloride-rich water from underlying aquifers, which as previously noted can "up well" during over-pumping of shallower aquifers. Lower chloride values, well under the MCL, are distributed throughout the study area.

**Figure 11. Boxplot for Chloride measurement distributions in BMU #2**

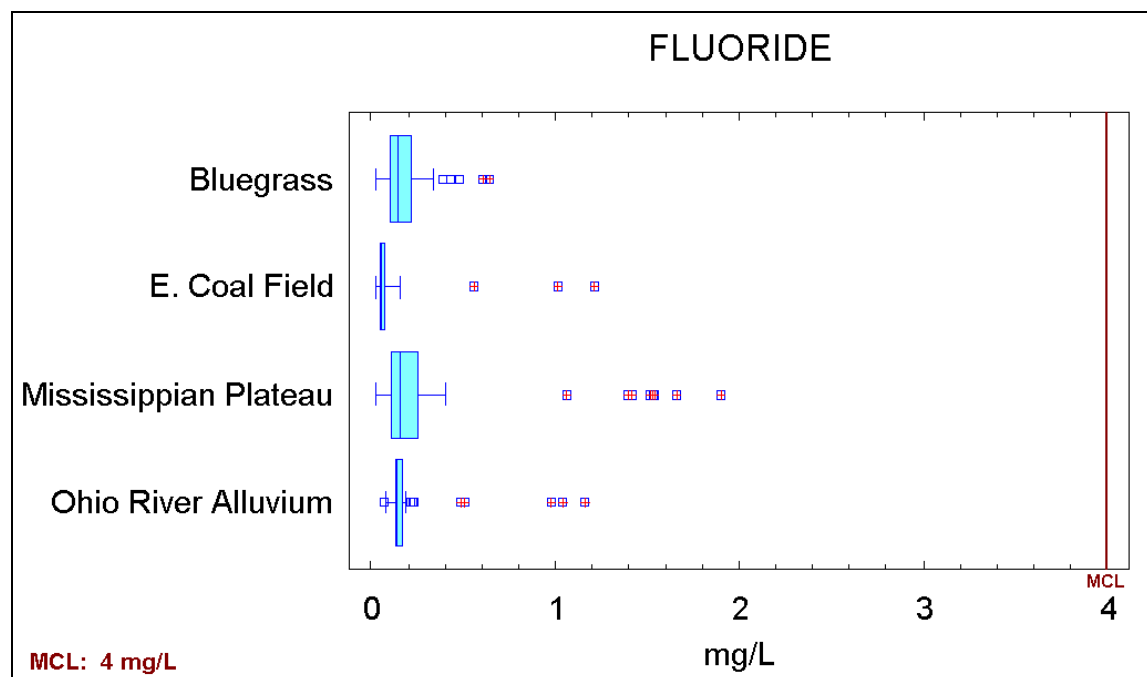


Fluoride (F<sup>-</sup>) commonly occurs in trace quantities in many soils and rocks, including coal. Fluorite (CaF<sub>2</sub>) is the primary fluorine mineral. Additionally, fluoride in the form of hydrogen fluoride enters the environment through atmospheric deposition from coal-fired power plants and from some manufacturing processes, especially aluminum smelting. Because small amounts of fluoride (1 ppm) in water help prevent tooth decay, public water systems often add this to their water. Some researchers claim this practice is potentially harmful and therefore the efficacy of drinking water fluoridation is a widely debated issue. The MCL for fluoride is 4 mg/L. Exposure to excessive amounts of fluoride can result in dental and skeletal fluorosis. Brittle, mottled and discolored tooth enamel characterizes dental fluorosis. Skeleton fluorosis causes a wide range of muscle and bone problems, including osteoporosis.

Figures 13 and 14 indicated that fluoride showed a narrow range of values for most of the data. Because no apparent nonpoint sources of fluoride other than possible effects from atmospheric deposition were noted, outliers may be indicative of natural variability. No sample analysis results exceeded the MCL and no specific sites are known to have been impacted by nonpoint source pollution. Since



**Figure 13. Boxplot for Fluoride measurement distributions in BMU #2**

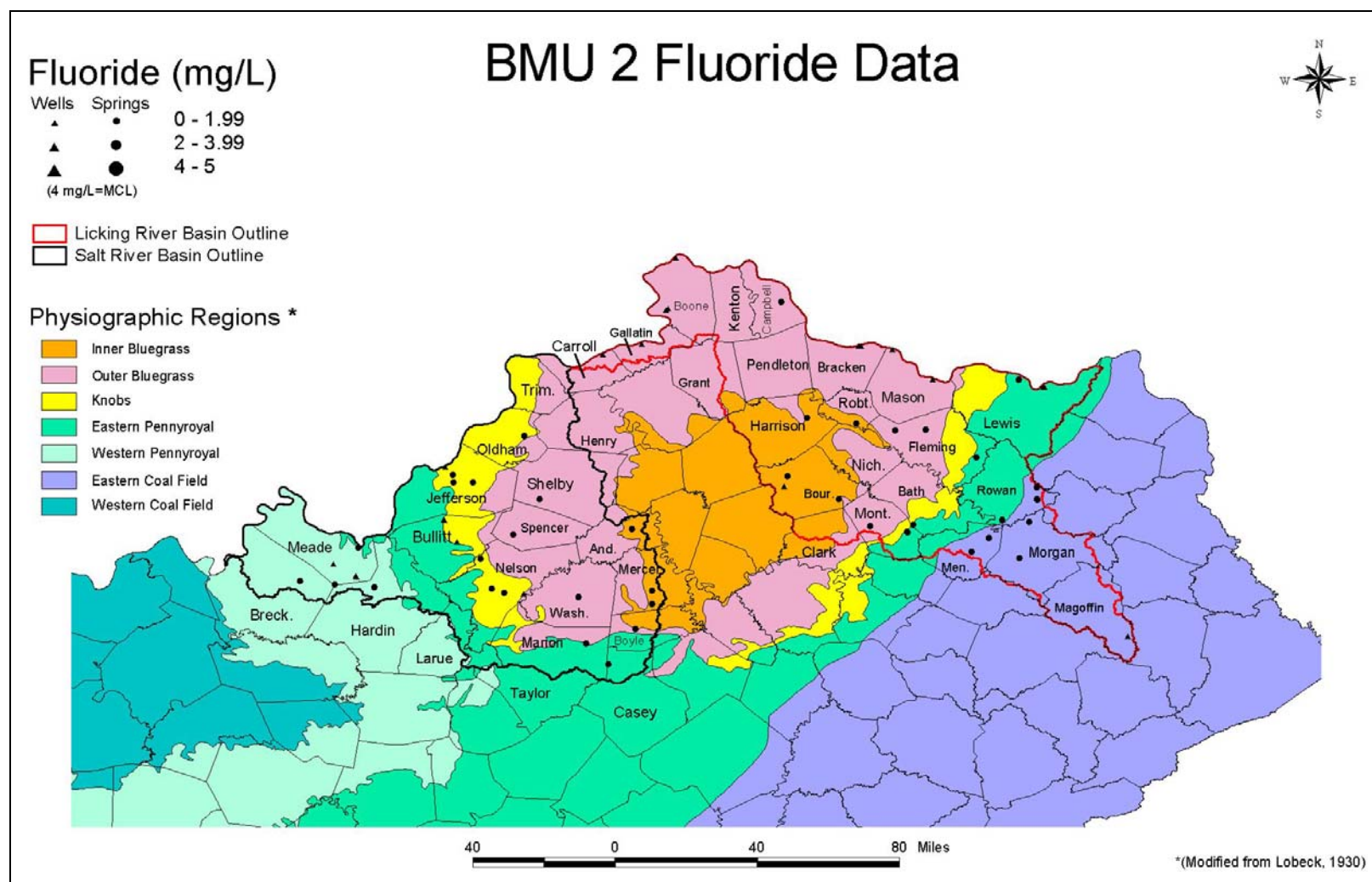


reference sites may also be impacted by possible atmospheric deposition, comparison with these sites may be invalid.

Conrad and others (1999a) compiled and analyzed statewide fluoride data. They reviewed 4,848 records from 2,630 sites and found only 24 analyses from 16 sites that exceeded the MCL. Two of these sites were in BMU 2; one in Mercer County and one in Gallatin County. Sites in this study in those counties failed to confirm the values found in the 1999 study, but does not necessarily indicate an improvement in groundwater quality.

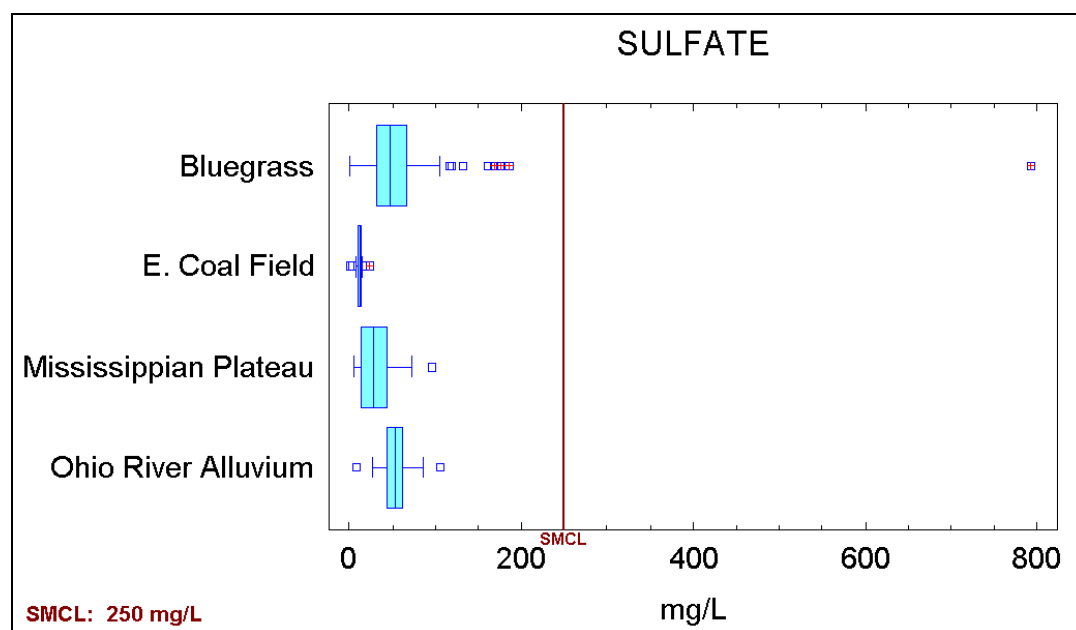
Sulfate ( $\text{SO}_4$ ) typically dissolves into groundwater from gypsum (hydrous calcium sulfate) and anhydrite (calcium sulfate), from the oxidation of several iron sulfides, such as pyrite ( $\text{FeS}$ ) and from other sulfur compounds. In the project area sulfate is common and naturally occurring, and therefore it is not a good indicator of nonpoint source pollution. Sulfate has an SMCL of 250 mg/L and amounts greater than this impart distasteful odor and taste to the water and commonly have a laxative effect.

In general, Figure 15 illustrates a narrow range of sulfate values, well under the SMCL, especially



**Figure 14. Map of Fluoride Data for BMU 2**

**Figure 15. Boxplot for Sulfate measurement distributions in BMU #2**



in the Eastern Coal Field. The far outlier of approximately 800 mg/L in the Bluegrass is the Arrasmith well in Boone County, shown in Figure 16. This well is located in the thinly bedded shale and limestone terrane of the Outer Bluegrass where water quality is often naturally high in dissolved solids, especially sulfate. The existence of highly mineralized groundwater in this area is also supported by the occurrence of several nearby natural mineral springs. These springs are commonly known as "licks" because of the wild animals that lick the mineral rich water and soils. One such spring occurs at Big Bone Lick State Park in Boone County, about two miles south of the Arrasmith well.

Because there is no direct evidence of nonpoint sources of sulfate affecting the groundwater sites in this study and because sulfate is commonly naturally occurring in groundwater throughout the study area, this parameter was not found a useful indicator of nonpoint source pollution. Although coal mining is known to affect groundwater in some areas of BMU 2, this study does not confirm that. However, data in the Eastern Coal Field are limited and if other sites had been sampled immediately adjacent to current or historical coal-mining areas, the results might have supported different conclusions.



## Metals

Groundwater samples were analyzed for arsenic, barium, iron, manganese and mercury. These metals were chosen because they are common constituents of sedimentary rocks, especially coal and black shales (USGS, 2002b; Tuttle and others, 2001) and soils (Logan and Miller 2002). In water, lower pH values, as well as higher dissolved oxygen content, increase the dissolution of metals. Common anthropogenic nonpoint sources of problem metals include mining, urban run-off, industrial operations, land farming of sewage and other waste and emissions from coal-fired power plants. High concentrations of metals in groundwater are sometimes difficult to interpret and may indicate point or nonpoint sources of contamination, or may even be naturally occurring. Comparison with reference reach springs (Table 2), as well as reviewing relevant literature, can prove useful.

A complete suite of total and dissolved metals was analyzed for each sample collected. Because MCL's are based upon total metal analysis, the results presented below are based upon total, rather than dissolved, concentrations. Although other metals, such as silver, vanadium and gold were analyzed, detections of these were exceedingly rare and invariably at very low levels. Consequently, these results are not presented here.

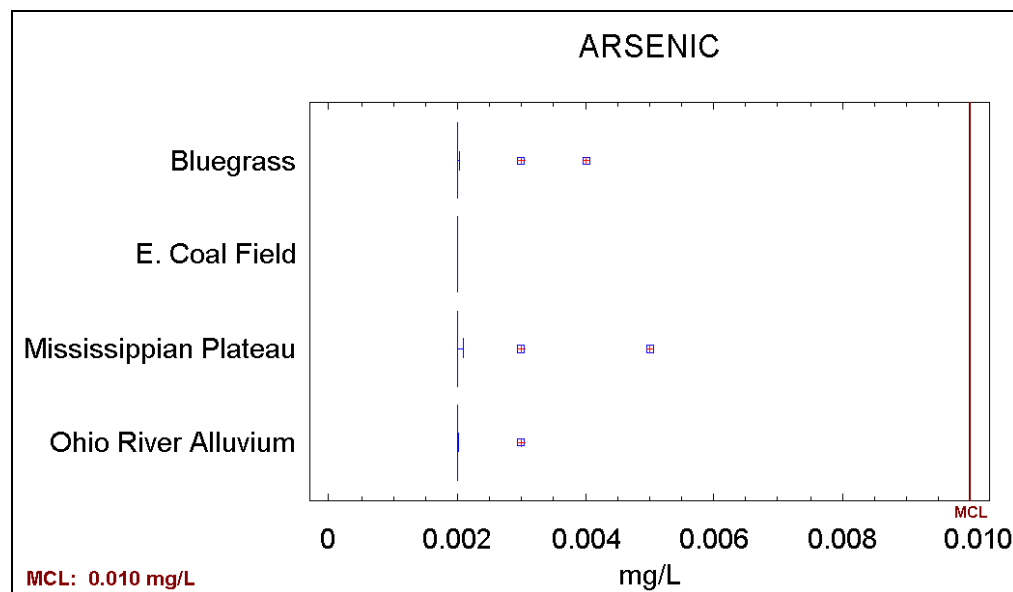
Arsenic is often found as a trace element associated with coal and shale (USGS, 2002b). In addition, the USGS (2002a) notes that the majority of arsenic in groundwater is the "... result of minerals dissolving from weathered rocks and soils." Blanset and Goodmann (2002) note that the "... most prominent source of arsenic in Kentucky's aquifers results from the oxidation of arsenopyrite, incorporated in iron hydroxides."

Other sources of arsenic include deposition from coal-fired power plants and metal-smelting/manufacturing processes, historical use in pesticides (U.S.EPA, 2002a) and from embalming fluid, especially from about 1860 until its use was banned in 1910 (Fetter, 1992). Arsenic occurs in organic and nonorganic forms and generally the latter are more harmful to human health. Arsenic exposure in humans has been linked to bladder and other cancers (USGS, 2000). Arsenic has an MCL of

0.010 mg/L. The U.S.EPA lowered this MCL from 0.05 mg/L in 2001 and will require public water systems to meet the new standard by January 2006.

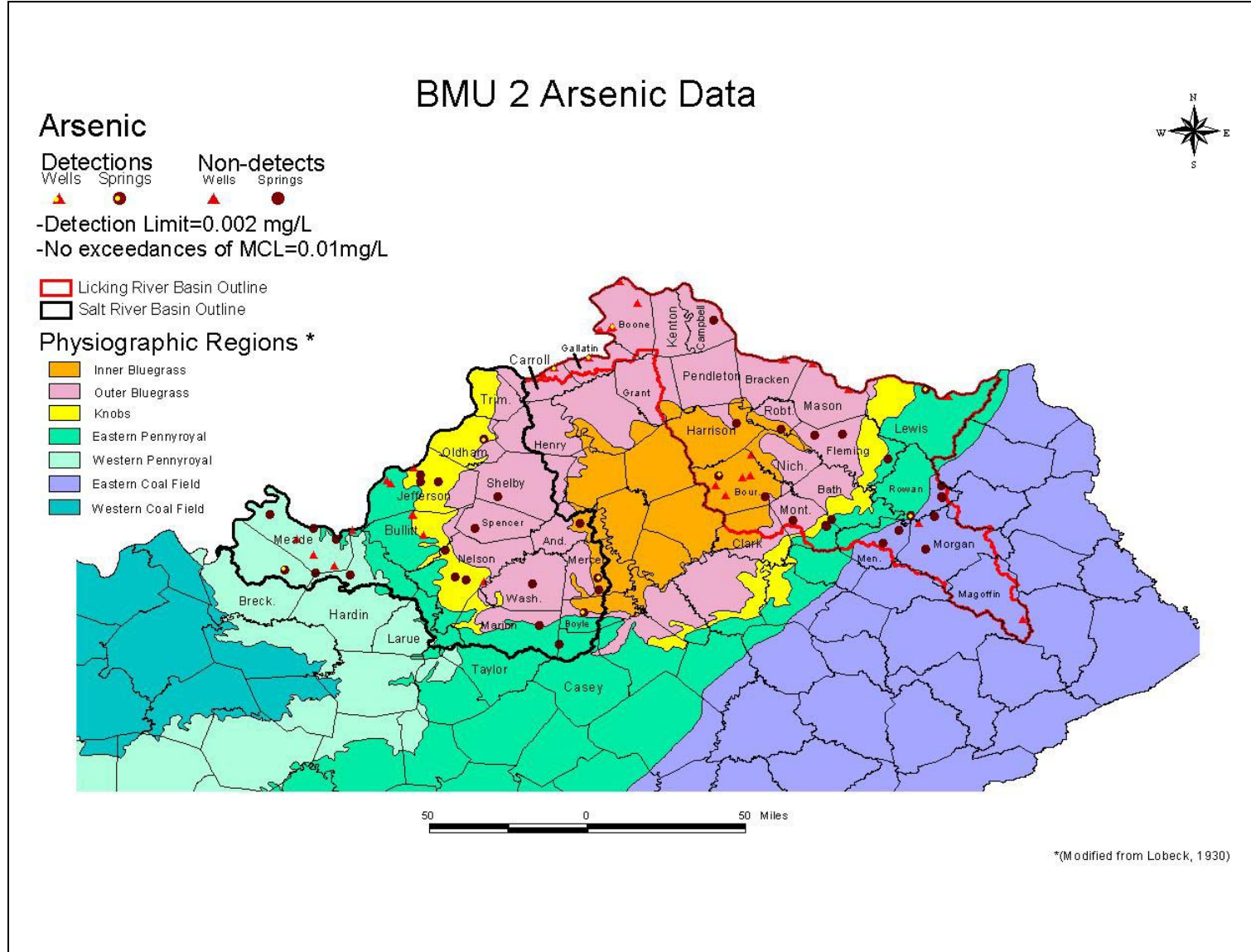
Arsenic was detected in 10 (approximately 4%) of the 225 samples. The detection limit for arsenic is 0.002 mg/L; figures 17 and 18 indicate that most samples were not detectable at this limit.

**Figure 17. Boxplot for total arsenic measurement distributions in BMU #2**



There were only 5 outliers and the other 5 detections are within 1.5 times the IQR for arsenic, indicating that there is not a wide range in these result values. The largest concentration of arsenic was 0.005 mg/L, from a spring in the Mississippian Plateau region, but this value is still well below the MCL of 0.010 mg/L. Subsequent samples taken at this site show concentrations less than the MDL of 0.002 mg/L.

Fisher (2002) reviewed statewide arsenic data and found that for ambient groundwater about 95% of 4,402 analyses from 930 sites were less than the MCL of 0.010 mg/L. Blanset and Goodman (2002) reviewed total arsenic data from 1,249 ambient groundwater samples from 240 sites and found 10 sites with total arsenic exceeding the MCL of 0.010 mg/L. In their study, Blanset and Goodman concluded that alluvial aquifers were most at-risk through the reduction of arsenic containing iron hydroxides. Our



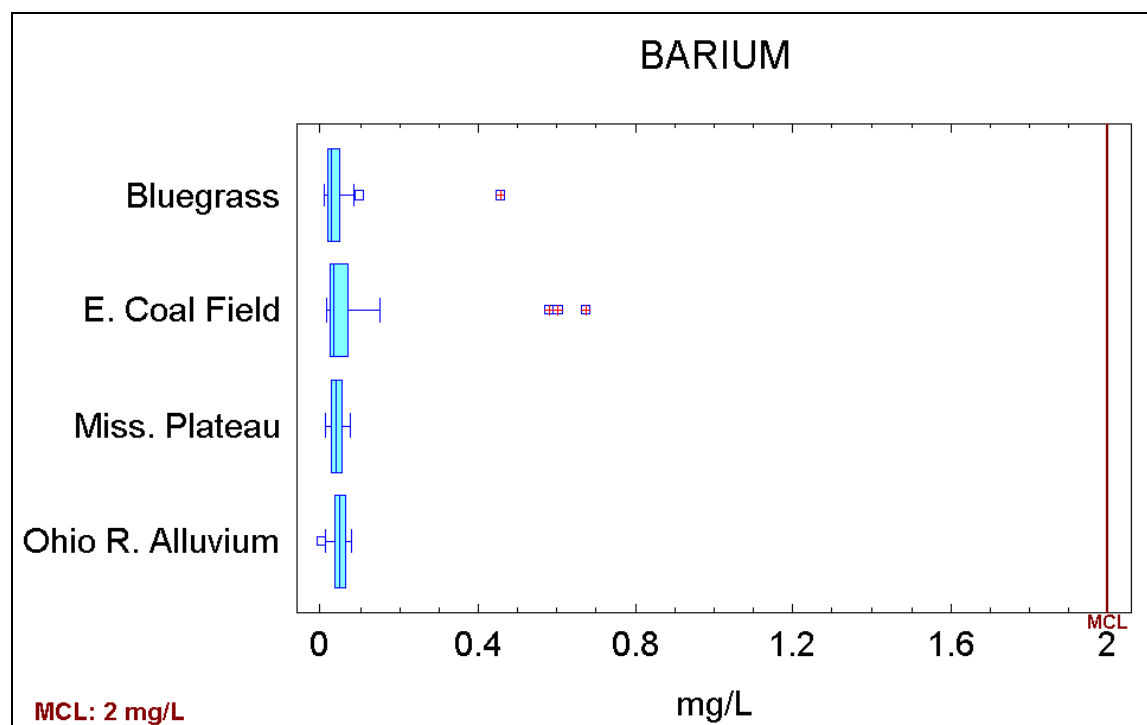
**Figure 18. Map of Arsenic Data for BMU 2**

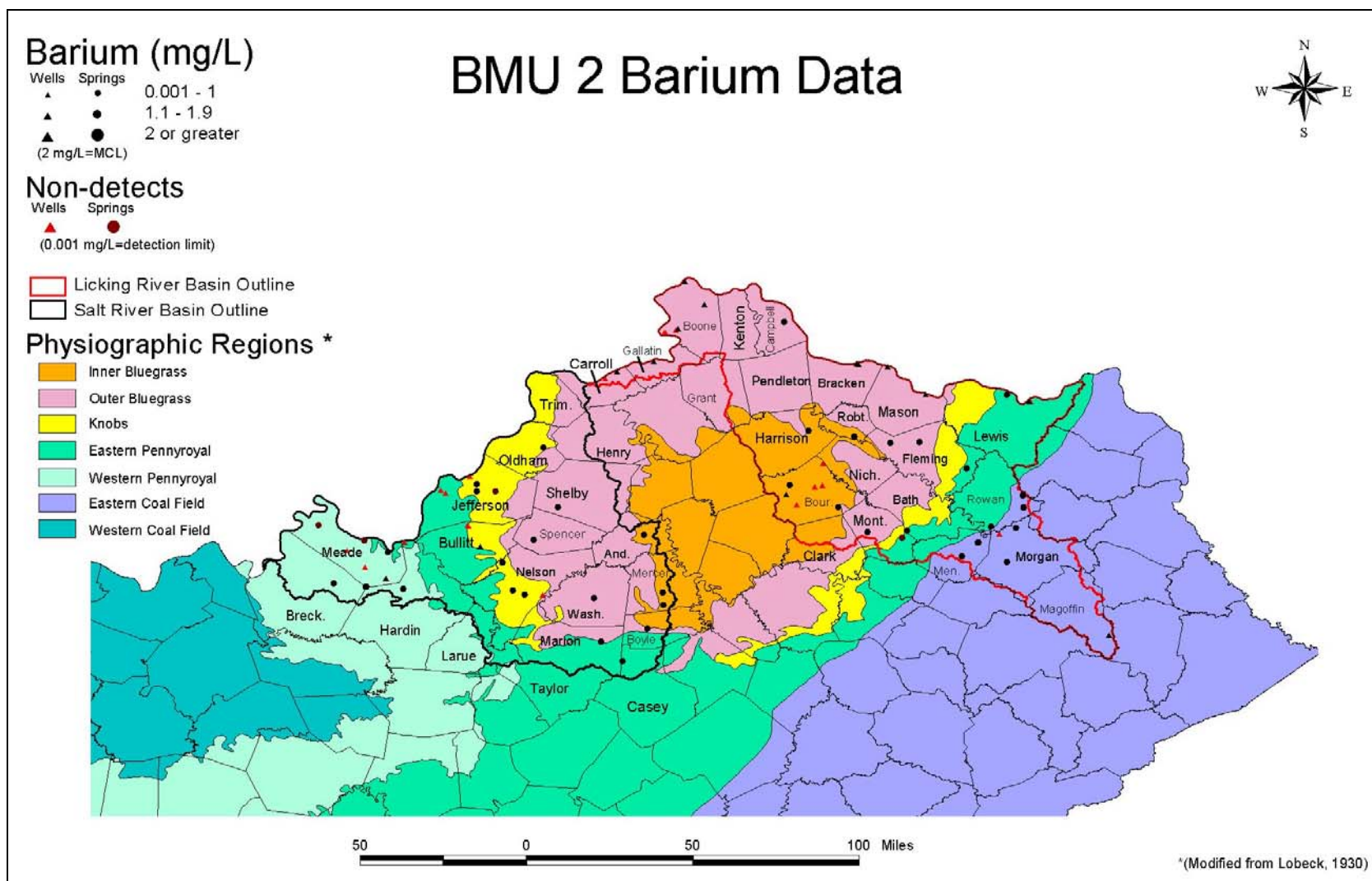
study, however, found no differences in the occurrence of arsenic between alluvial aquifers and other physiographic provinces, as shown in Figure 17. The low levels of arsenic found in our study, as well as the absence of any apparent sources, indicate no negative impacts through nonpoint source pollution in BMU 2.

Barium occurs most commonly as the mineral barite ( $\text{BaSO}_4$ ). This naturally occurring mineral occurs in nodules in sedimentary rocks and as a trace element in coal. Barite is particularly common in the Inner Bluegrass of central Kentucky. The drilling industry uses barium, and this mineral also occurs in a variety of products such as glass and paint. The MCL for barium is 2 mg/L and exposure to high levels of barium has been associated with cardiovascular problems such as high blood pressure.

Barium was found in almost all of the samples collected. However, most detections occurred within a narrow range in all physiographic provinces (Figures 19 and 20). Outliers reflect the natural

**Figure 19. Boxplot for barium measurement distributions in BMU #2**





**Figure 20. Map of Barium Data for BMU 2**

variability in the karst Bluegrass. Barium is known to occur naturally and at relatively high levels, often above the MCL, in the Eastern Coal Field (Wunsch, 1991). However, this study did not detect barium at such levels. Barium is not typically indicative of nonpoint source pollution and in the absence of any known nonpoint sources in the study area, barium occurrence in Kentucky represents natural groundwater quality.

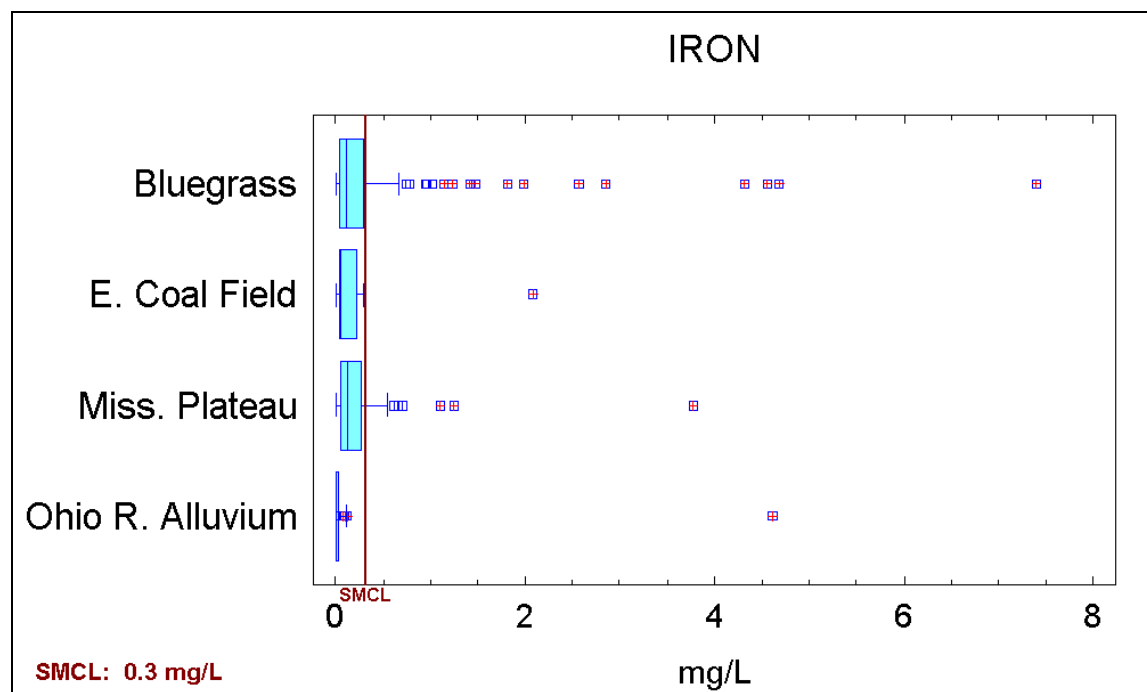
Iron (Fe) is commonly found in at least trace amounts in practically all sediments and sedimentary rocks (Driscoll, 1986). Iron is also one of the most prevalent groundwater quality problems in wells in Kentucky. However, in almost all cases, elevated iron is naturally occurring and therefore not generally diagnostic of nonpoint source pollution. One notable exception is that high levels of iron may be associated with run-off from coal mining. Typically, this high iron discharge affects surface water rather than groundwater, but wells in old mine works and adjacent areas can also be affected.

Iron is a basic water quality parameter regarding the suitability of water for drinking and industrial use. Iron helps transport oxygen in the blood and is essential for good health. Excessive iron in water used for human consumption is an aesthetic, rather than a health-based, concern. Iron has an SMCL of 0.3 mg/L.

Iron causes problems when it changes from the dissolved, or *ferrous*, state to the precipitated state, or as *ferric* iron. Precipitated iron can coat or encrust well screens and casing, pipes, pumping equipment and plumbing fixtures. Additionally, various metal-reducing bacteria that feed on iron can coat fixtures. Sometimes iron bacteria can grow to such an extent that a gelatinous mass is formed that can completely plug a well and associated equipment. Although iron bacteria are not usually a health problem, they do render the water unpalatable and are indicators of unsanitary conditions that may harbor other, more harmful, bacteria.

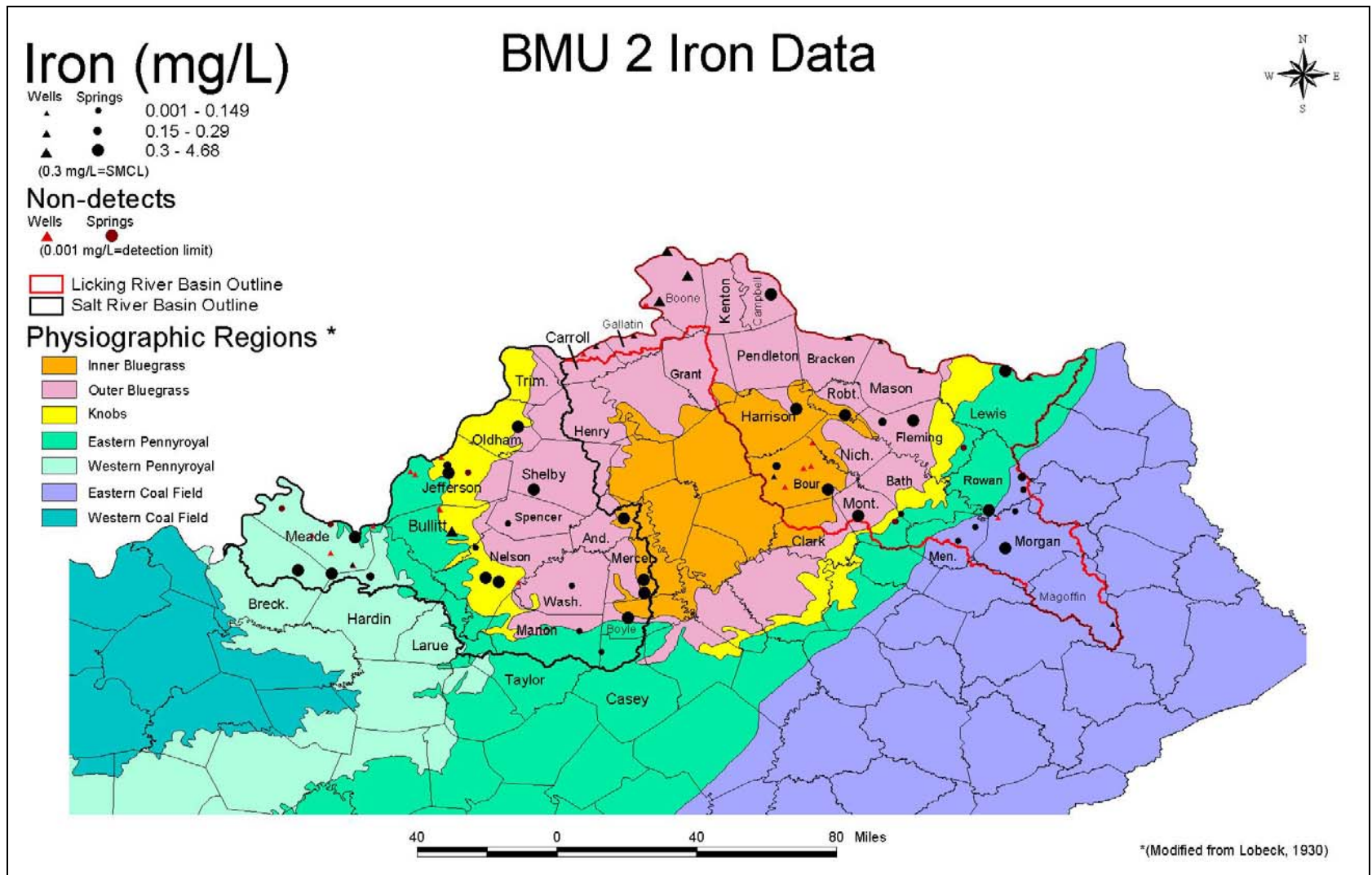
In this study, more than 87% of the samples had detections of iron (Figure 21), but most detections were less than the SMCL. Numerous outliers show the natural variability of this element. Given the absence of specific nonpoint sources of iron, Figure 21 indicates naturally occurring variations

**Figure 21. Boxplot for Iron measurement distributions in BMU #2**



in groundwater quality, rather than nonpoint source pollution. Figure 22 illustrates the wide-spread occurrence of iron throughout all physiographic provinces.

Manganese (Mn) is a relatively common element, but it occurs less abundantly in groundwater than does iron. Manganese is associated with discharges from coal mining and metal manufacturing. Manganese in water supplies can cause staining and encrustation of plumbing fixtures, piping and well screens, as well as discolored laundry. The MCL for manganese is 0.05 mg/L. Manganese is a common, naturally occurring, water quality problem in Kentucky. It occurs in more than 87% of the samples. As shown in Figure 23, values clustered in a narrow range just below the SMCL of 0.05 mg/L, but levels above this are common. Manganese is generally not a direct indicator of nonpoint source pollution. Mayes Spring in Boyle County (Bluegrass) had the highest level of manganese found in this study and is the outlier shown in Figure 23 at about 12 mg/L. The reason for this unusually high value, unconfirmed by other samples at this site, is unknown.



**Figure 22. Map of Iron data for BMU 2**

**Figure 23. Boxplot for manganese measurement distributions in BMU #2**

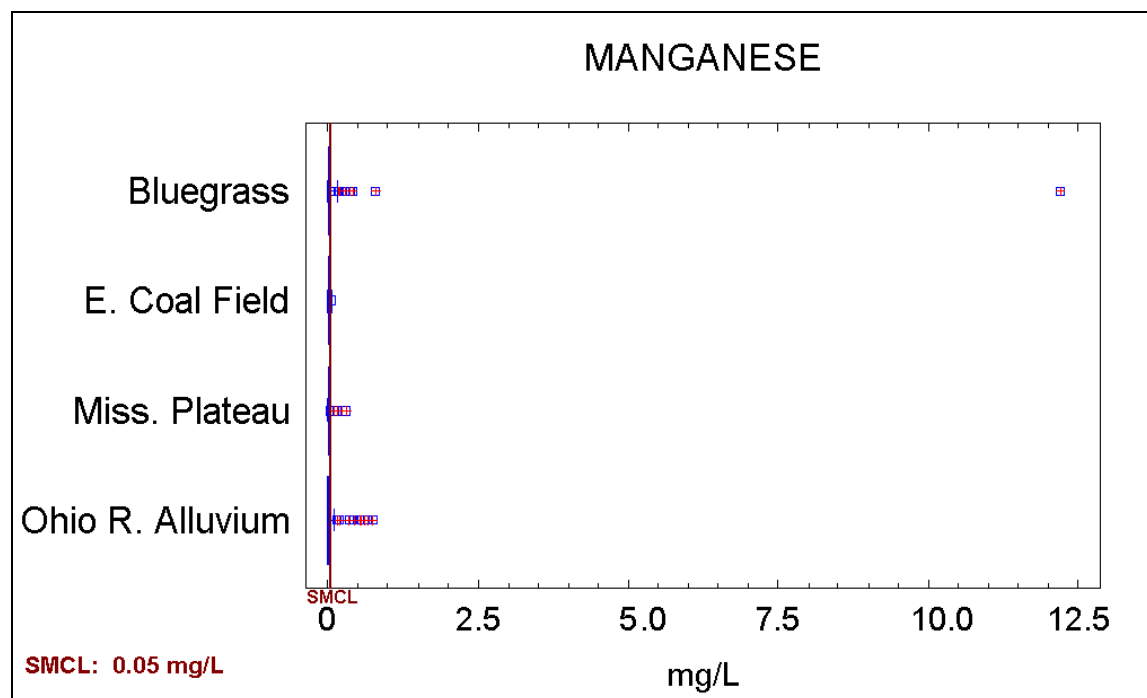
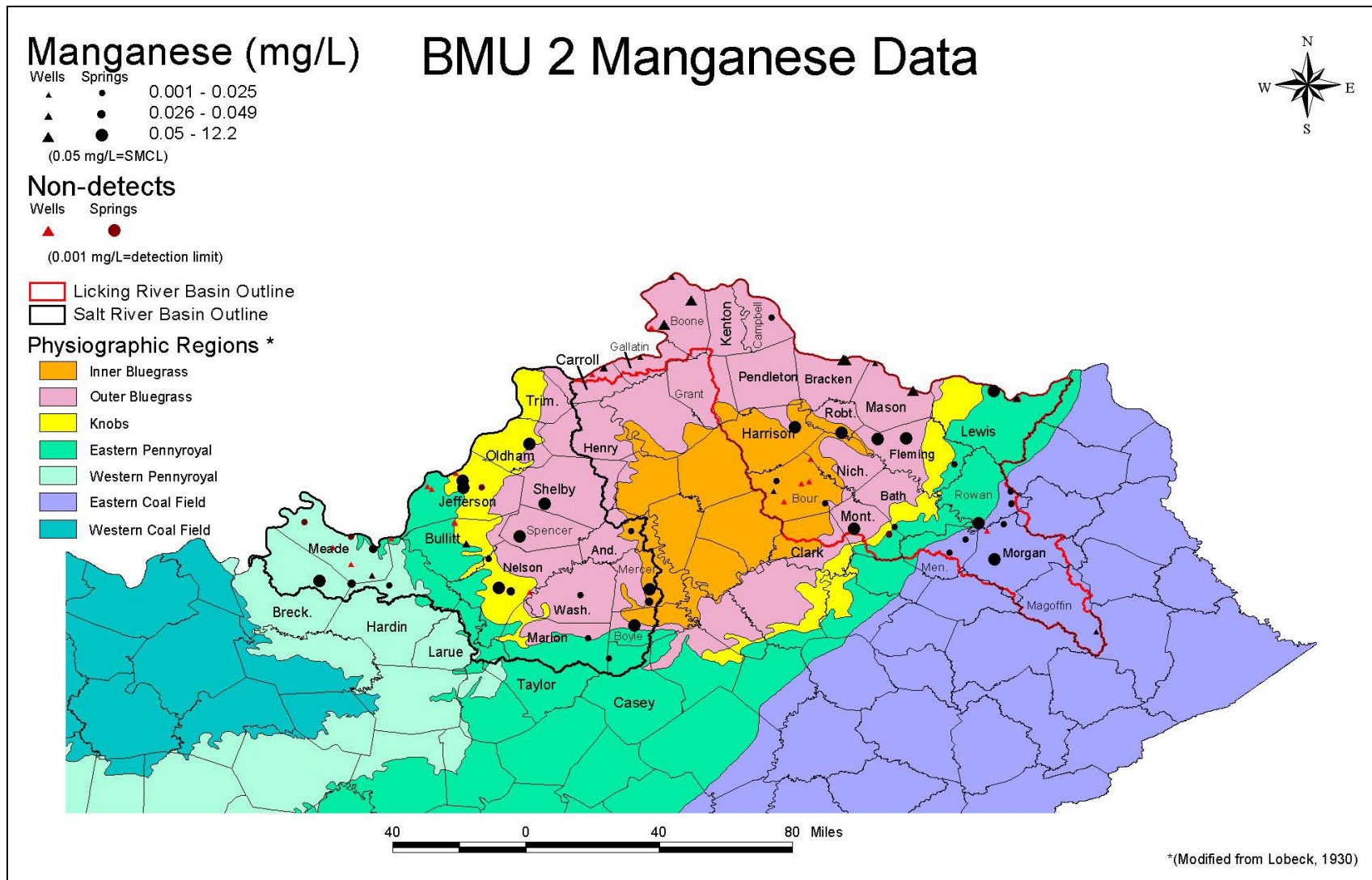


Figure 24 shows the occurrence of manganese throughout the study area, with no apparent pattern of distribution among the various physiographic provinces.

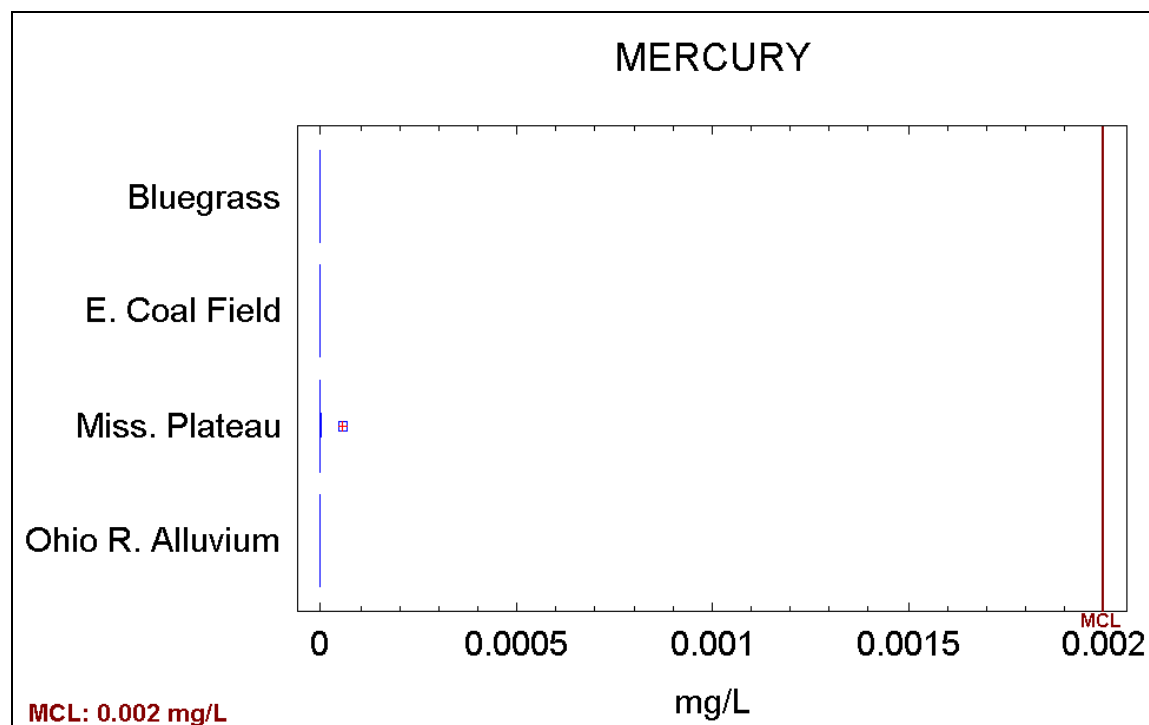
Mercury (Hg) occurs naturally in the Eastern Coal Field as a trace element in coal (USGS, 2002b). Primary nonpoint sources of mercury pollution are via atmospheric deposition from coal-burning power plants and boilers, waste incineration and manufacturing. The MCL for mercury is 0.002 mg/L.

Mercury occurred in 1 of 225 samples. This single detection, at McKenzie Spring in Rowan County, was 0.000056 mg/L, which is slightly above the DES method detection limit (MDL) of 0.00005 mg/L. No other samples at this site duplicated or exceeded this value and no source for mercury in this area was found. Because there was only this single detection of mercury, no map is presented. Mercury data indicate that this metal does not occur naturally in groundwater in the study area, nor does it occur in groundwater through air-borne deposition from coal-fired power plants or other sources.



**Figure 24. Map of Manganese data for BMU 2**

**Figure 25. Boxplot for mercury measurement distributions in BMU #2**



Although the Division of Water has issued statewide fish consumption advisories for mercury, groundwater in BMU 2 does not appear to contribute to this surface water problem. However, only a limited data set of 15 mercury samples were analyzed for the Eastern Coal Field. Because mercury occurs as a trace element in coal and because air-borne deposition from coal-fired power plants is on going, additional sampling should include mercury to fully determine the potential long-term impacts of this metal on groundwater.

### Pesticides

Five commonly used pesticides are included in this report: atrazine, metolachlor, cyanazine, simazine and alachlor. Because these pesticides do not occur naturally and because their introduction into the environment from point sources such as leaking tanks is relatively limited geographically, the detection of pesticides in groundwater indicates nonpoint source pollution.

Atrazine was the most frequently detected pesticide, found in 15.5% of 342 samples analyzed. Metolachlor was the next most frequently detected pesticide, detected in about 10% of the samples. Alachlor and simazine were each detected in about 3% of the samples. Cyanazine was not detected in 314 samples. This information is summarized in tabular form in Appendix D.

Detection limits for the pesticides discussed in this report vary widely, depending on the laboratory method used, as shown in Table 4.

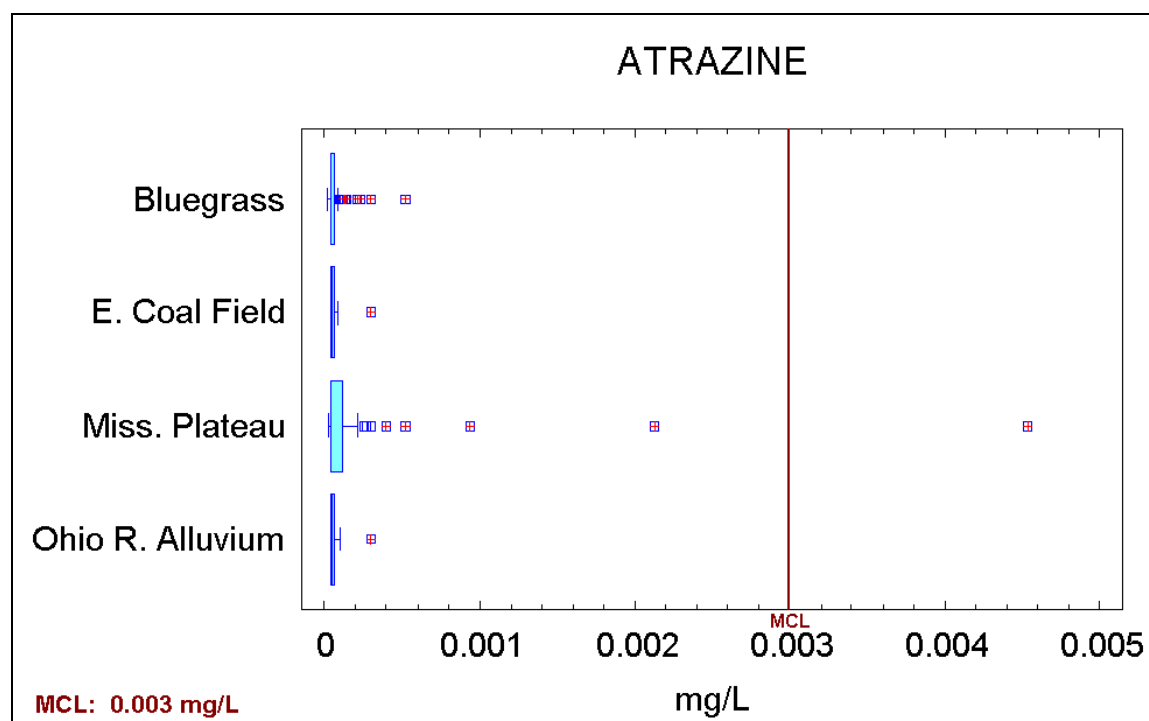
**Table 6. Pesticide Method Detection Limits**

| <b>Pesticide</b> | <b>Method Detection Limit Used for Samples, mg/L</b> |
|------------------|------------------------------------------------------|
| Atrazine         | 0.0003, 0.00004, 0.00005                             |
| Metolachlor      | 0.00002, 0.00004, 0.00005, 0.00006, 0.00008          |
| Cyanazine        | No detects at any MDL; 0.00004 most frequent MDL     |
| Simazine         | 0.0003, 0.00004, 0.00005                             |
| Alachlor         | 0.00002, 0.00004, 0.00005, 0.00006                   |

Atrazine (most commonly sold under the trade name AAtrex or simply Atrazine) is used primarily for weed control for corn and soybean production and is one of the most commonly-used herbicides in Kentucky. In 1999, when this study began, approximately two million pounds of atrazine were sold in Kentucky (KDA, 200). Atrazine has an MCL of 0.003 mg/L. Atrazine is a carcinogen and exposure to excess amounts is associated with weight loss, cardiovascular damage and degeneration of muscle tissue and the retina. Atrazine has also recently been suspected to cause hermaphroditism in frogs (Hayes and others, 2002).

Not surprisingly, atrazine was most often detected in agricultural areas characterized by row crop production, primarily in the Bluegrass and Mississippian Plateau (Figure 26). Karst springs in particular are vulnerable to pesticide contamination via surface water runoff to sinkholes, sinking streams and macroporic flow through soils. The variability of pesticide levels in karst areas, such as the Mississippian Plateau, reflects the variability of flow in quick recharge/quick discharge karst systems. The occurrence

**Figure 26. Boxplot for atrazine measurement distributions in BMU #2**



of atrazine is rare in the Eastern Coal Field where row cropping is limited.

Figure 27 illustrates the occurrence of atrazine in BMU 2. The highest occurrence and the only detection of any pesticide above MCL, was 0.004535 mg/L at Big Spring in Breckinridge County, which is a karst window in an area of row crops (Figures 26 and 27). Atrazine was also detected at 1 other site besides Big Spring in the Mississippian Plateau as well as at 13 sites in the Bluegrass and at 3 sites in the Ohio River Alluvium. All sites with atrazine detections were in agricultural areas including row crops, except for two urban springs in the Bluegrass: Cat Spring in Oldham County and Jesse's Spring in Jefferson County. Cat Spring is adjacent to a farm supply store and this may explain the detection of atrazine; Jesse's Spring is in a residential area where atrazine application is less likely to occur.

Metolachlor (trade names include Bicep II Magnum and Dual II Magnum) is used as a pre-emergent and pre-plant weed control for the production of corn and soybeans. In 1999, approximately 800,000 pounds of metolachlor (combined metolachlor and s-metolachlor)

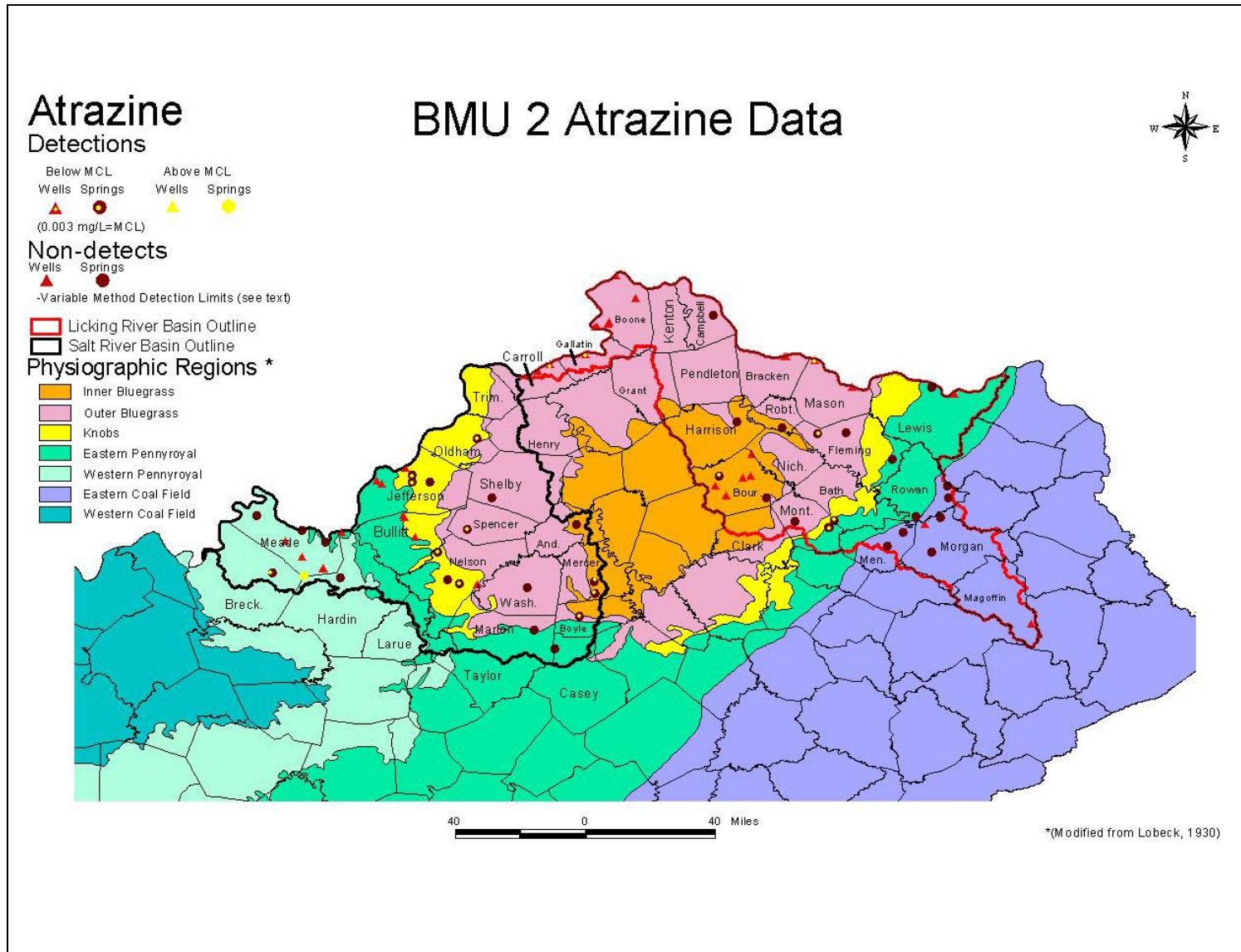
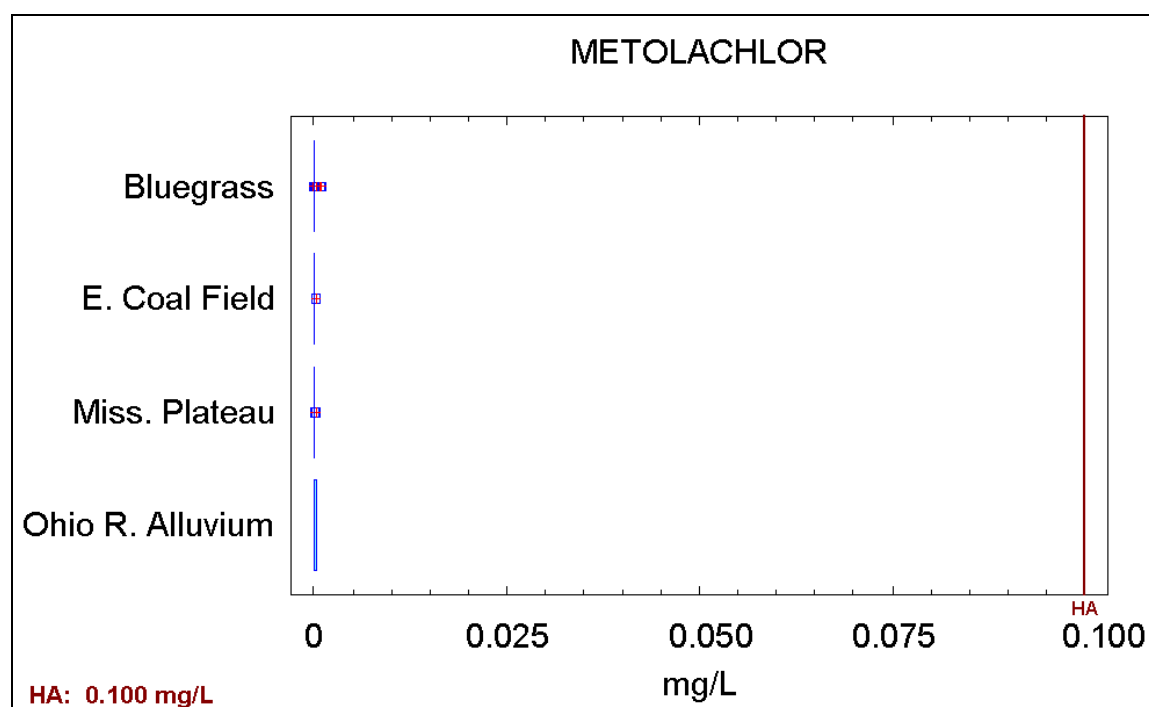


Figure 27. Map of Atrazine data for BMU 2

were sold in Kentucky (KDA, 2000). Metolachlor is a possible human carcinogen and has an HAL of 0.1 mg/L.

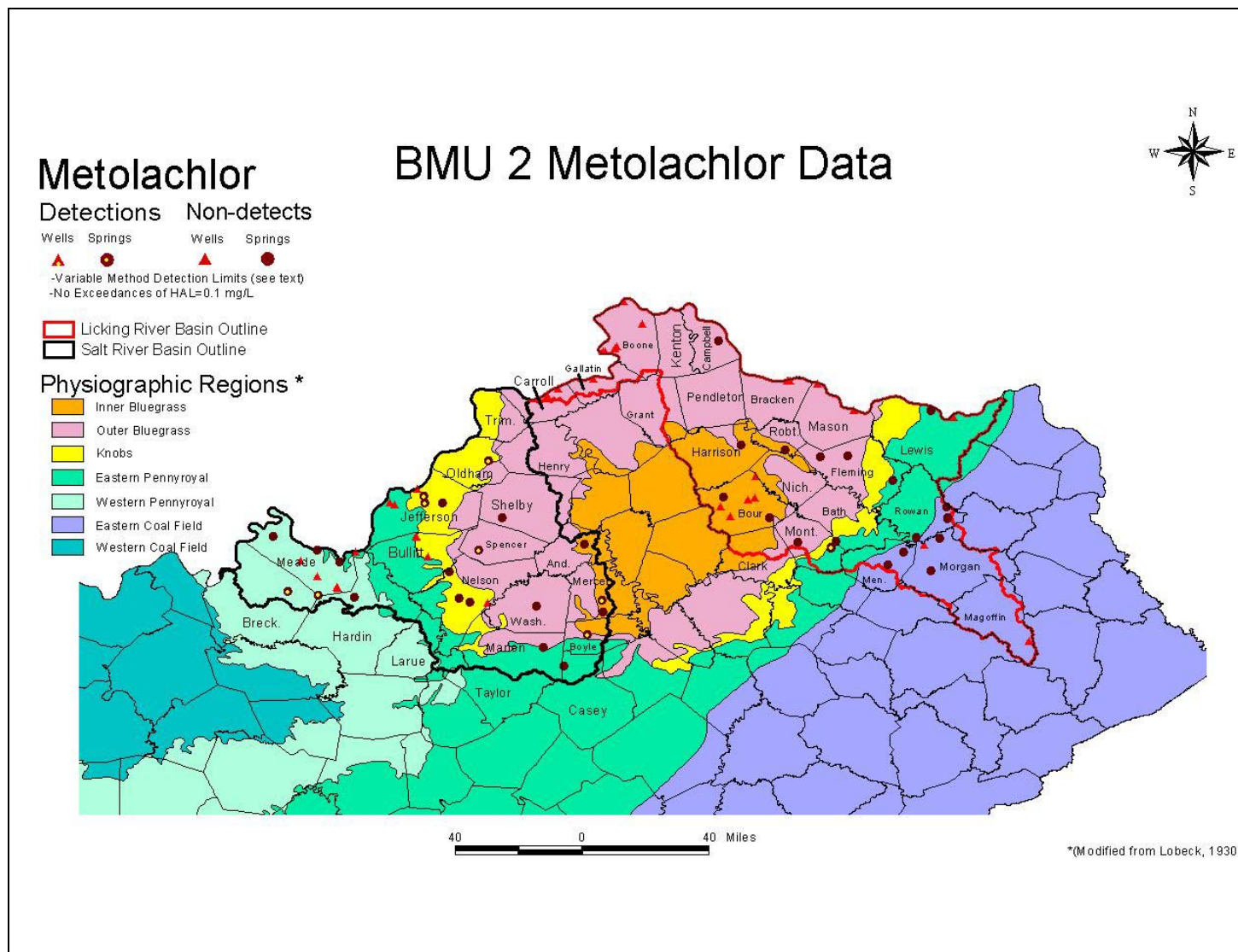
Metolachlor occurred at very low levels in approximately 10% of the samples analyzed (Figure 28). There was virtually no variation between the physiographic regions (Figure 29) and the range of

**Figure 28. Boxplot for metolachlor measurement distributions in BMU #2**



values was narrow. Metolachlor was not detected above its HAL. Although the number of detections of this herbicide does indicate nonpoint source pollution, the low levels showed minimal impacts to groundwater quality.

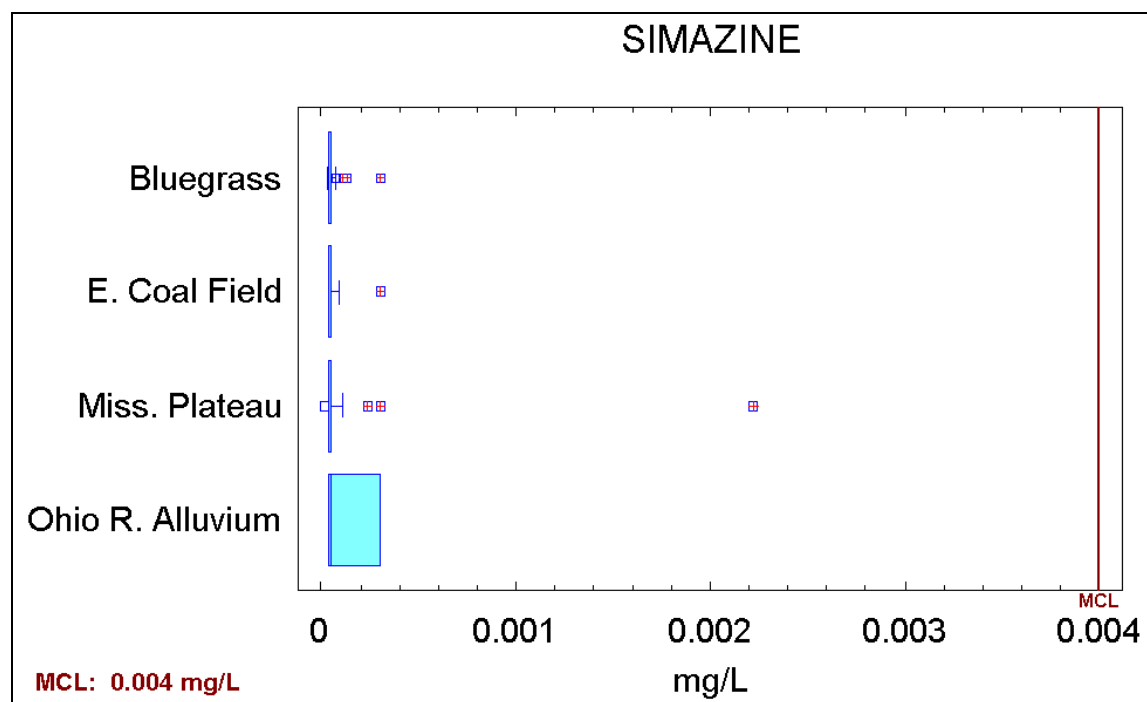
Simazine (trade names include Princep) is used to control annual nuisance grasses and broadleaf weeds, especially for corn and alfalfa production. In humans, simazine is carcinogenic and exposure to simazine is associated with tremors, damage to liver, testes, kidneys and thyroid and gene mutation. Simazine has an MCL of 0.004 mg/L.



**Figure 29. Map of Metolachlor data for BMU 2**

Simazine occurred in approximately 3% of the samples, but never above the MCL. The highest occurrence was in the Mississippian Plateau (Big Spring, Breckinridge County) at about half the MCL. Simazine was detected sporadically in the Bluegrass, Eastern Coal Field and Mississippian Plateau (Figures 30 and 31).

**Figure 30. Boxplot for Simazine measurement distributions in BMU #2**



Alachlor (trade names include Bullet and Micro-Tech) is used for corn and soybean production for pre-emergent weed control. Alachlor has an MCL of 0.002 mg/L. Alachlor has been associated with cancer in humans and has also been linked with noncancerous effects in the liver, spleen and kidneys.

Alachlor occurred at eight sites in this study, but never above the MCL (Figure 32). As shown in Figure 33, alachlor was found at 3 sites each in the Bluegrass and Mississippian Plateau and at 2 sites in

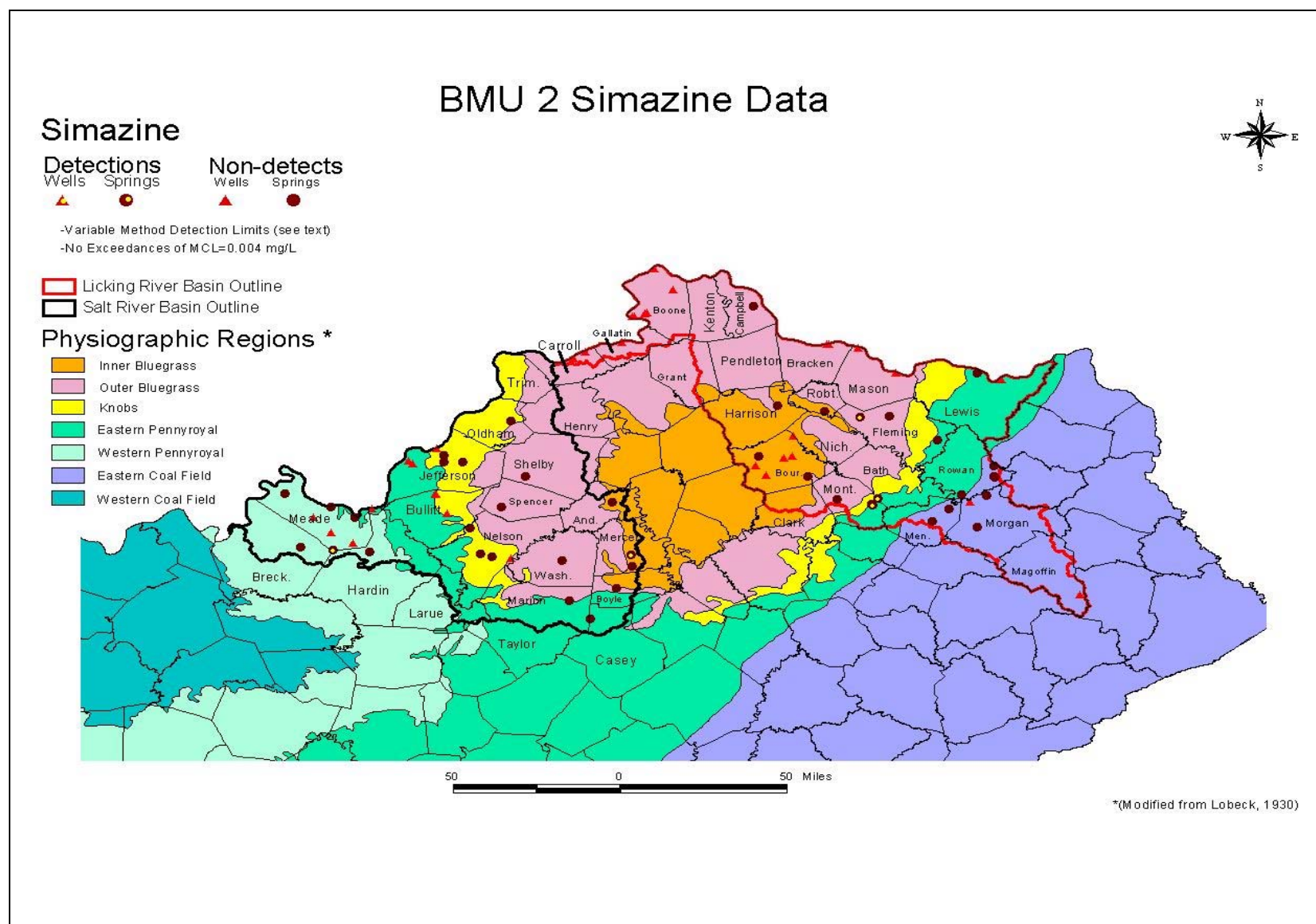
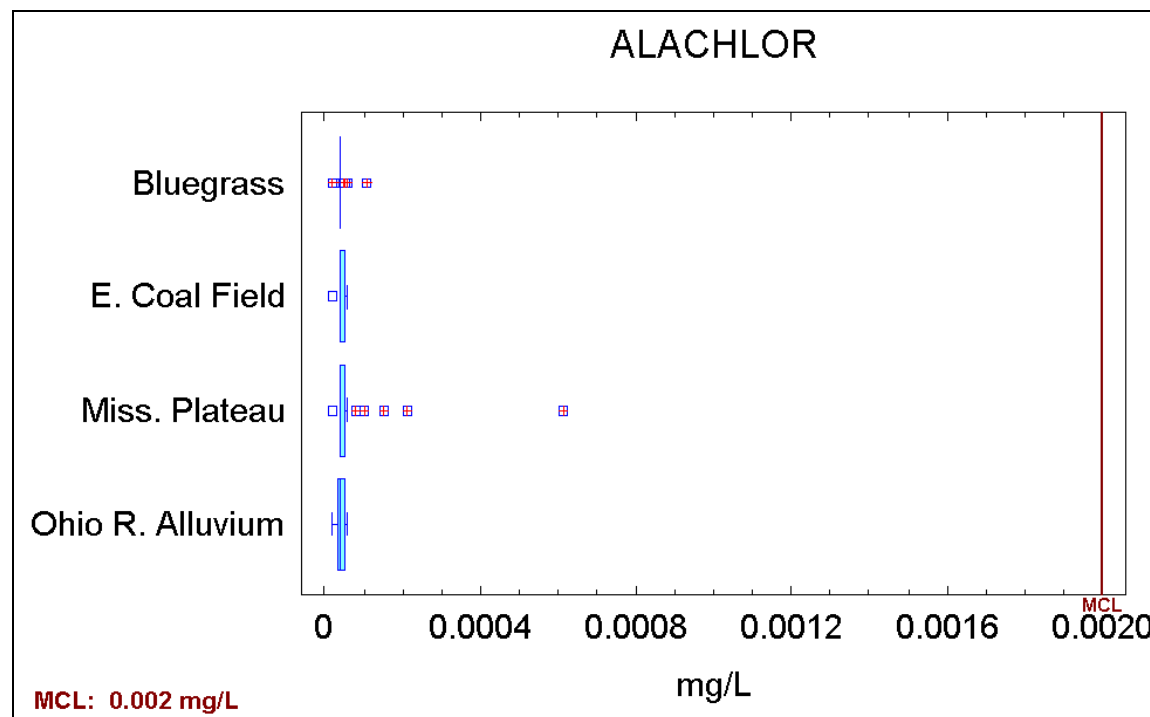


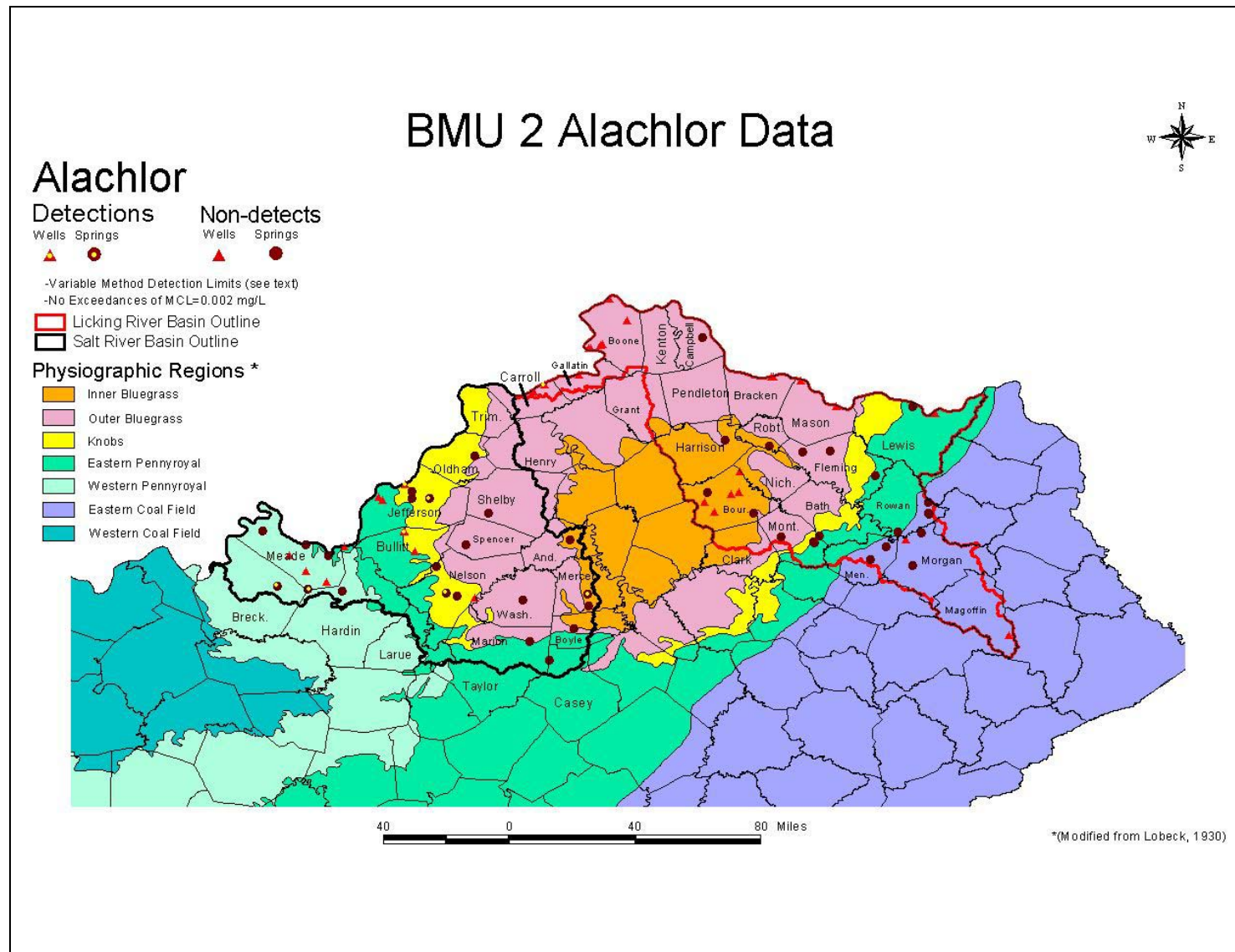
Figure 31. Map of Simazine data for BMU 2

the Ohio River Alluvium. The maximum detected value was at Big Spring in Breckinridge County at less than one-third of the MCL. Based upon its limited occurrence, alachlor has apparently had minor impacts on groundwater in this area.

**Figure 32. Boxplot for Alachlor measurement distributions in BMU #2**



Cyanazine production ceased in December 1999 and the sale and use of this herbicide was prohibited effective September 2002. Cyanazine was not detected in this study. The number of samples analyzed is presented in Appendix D.



**Figure 33. Map of Alachlor data for BMU 2**